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VIRGINIA GEOLOGICAL SURVEY
UNIVERSITY OF VIRGINIA
THOMAS LEONARD WATSON, PH. D.
DIRECTOR

Bulletin No. III-A

Geology of the Titanium and Apatite Deposits of Virginia

BY
THOMAS LEONARD WATSON AND STEPHEN TABER

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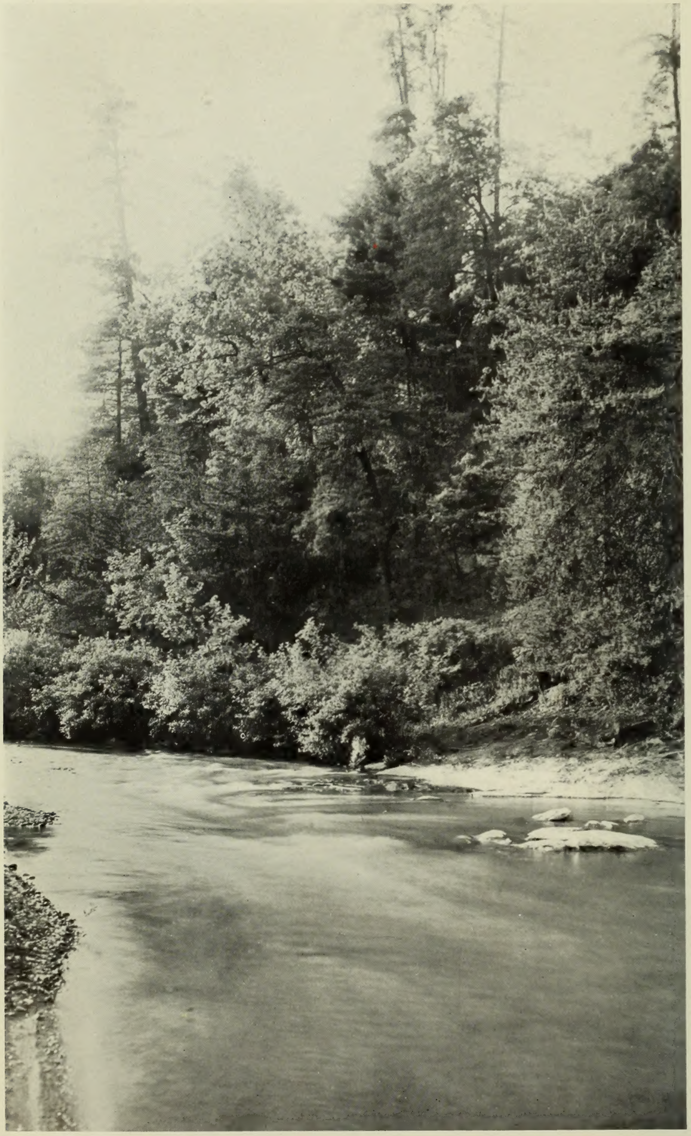

Piney River near Rose's Mill.

PINEY RIVER.

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THOMAS LEONARD WATSON AND STEPHEN TABER

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UNIVERSITY OF VIRGINIA
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Director of the Survey.

CONTENTS

PAGE

PREFACE xv
  Field work xv
  Scope of the report xv
  Acknowledgments xvi

TITANIUM: ITS HISTORY, CHEMISTRY, ORES AND DISTRIBUTION AND OCCURRENCE 1
  History 1
  Chemistry 1
    General properties 1
    Methods of preparation 2
  Compounds of titanium 4
  Mineralogical forms of titanium 5
  Titanium ores 5
    Oxides 6
      Rutile 6
    Titanates 7
      Ilmenite 7
    Ferrates 8
      Magnetite 8
    Table of titanium minerals 9
  Distribution and occurrence of titanium 12

OCCURRENCE AND GEOGRAPHIC DISTRIBUTION OF RUTILE WITH DESCRIPTION OF AREAS 14
  Mode of occurrence 14
    General statement 14
    Rock associations 14
      Igneous rocks 14
      Sedimentary rocks 15
      Metamorphic rocks 15
      Other forms of occurrence, veins, pegmatites, etc 16
    Mineral associations 17
    Alteration of rutile 17
  Geographic distribution of rutile 18
    General statement 18
    United States 19
      New England States 19
        Connecticut 19
        Maine 20
        Massachusetts 20
        New Hampshire 20
        Vermont 20
      Middle Northern States 20
        New Jersey 21
        New York 21
        Pennsylvania 21
      Southeast Atlantic States 22
        Alabama 22
        Georgia 23
          Graves Mountain 23
            Location and topography 23
            Geology 24
            Rutile 25
        The Carolinas 27
          North Carolina 27
          South Carolina 28

PAGE
States west of the Mississippi 29
Arkansas 29
California 29
Colorado 29
South Dakota 30
Texas 31
Canada 31
Quebec 31
St. Urbain deposits 31
Other localities 33
Nova Scotia 34
Ontario 34
Yukon Territory 34
Australia 34
Queensland 34
South Australia 35
Norway 37
Kragerö 37
Introduction 37
General description 38
Microscopic character 39
Chemical composition and classification 40
GEOLOGY OF THE ORE-DEPOSITS OF THE AMHERST-NELSON COUNTIES REGION 42
Location 42
Districts (subdivisions) 42
Roseland district 42
Lovingston district 44
Davis Creek district 44
Topography 44
Weathering 46
History of mining 47
Production 50
Uses 51
Prices 52
Literature 52
General geology and petrography 56
General statement 56
Principal rock groups 57
Areal distribution 58
Biotite-quartz monzonite-gneiss 59
Distribution and lithologic characters 59
Distribution 59
Lithologic characters 59
Microscopic character 61
Chemical composition and classification 63
Quartz veins 66
Syenite 68
General statement 68
Distribution 70
Megascopic character 70
Microscopic character 72
Chemical composition 75
Classification 78
Variations in the syenite 80
Contacts 84
Gneiss-syenite contact on the southeast side 84

PAGE
Gneiss-syenite contact on the northwest side 86
Mars Mountain 90
Gabbro 91
Distribution 91
Megascopic character 91
Microscopic character 92
Chemical composition and classification 94
Details of occurrences 97
Nelsonite 100
Name 100
Distribution 101
Megascopic character 101
Size, shape, and structure of the bodies 102
Mineral composition 103
Varieties 104
General microscopic characters 104
Weathering 105
Ilmenite nelsonite 106
Distribution 106
Megascopic character 106
Microscopic character 107
Chemical composition and classification 109
Details of occurrences 111
Rutile nelsonite 117
Name and distribution 117
Megascopic character 117
Microscopic character 118
Chemical composition and classification 120
Other localities 122
Magnetite and biotite nelsonites 123
Name and distribution 123
Megascopic character 123
Microscopic character 124
Chemical composition and classification 124
Other occurrences 127
An exceptional facies 130
Hornblende nelsonite 133
Name and lithologic character 133
Microscopic character 134
Chemical composition and classification 135
Other occurrences 137
Gabbro-nelsonite 138
Name and distribution 138
Megascopic character 138
Microscopic character 139
Chemical composition and classification 140
Details of occurrences 143
Chemical composition of the nelsonites 145
Classification 148
Old system of classification 148
New quantitative system of classification 148
Classification of nelsonites compared with that of titaniferous magnetites 150
Genesis 151
Summary of quantitative classification of nelsonites 155
Diabase 155
Introductory statement 155

PAGE

- Distribution and lithologic characters 156
- Microscopic character 156
- Chemical composition and classification 157
- Details of occurrences 159

INDIVIDUAL DESCRIPTION OF MINING PROPERTIES 161

- General statement 161
- American Rutile Company's quarries 161
  - Location and history 161
  - Production and uses 163
  - Geological relations 163
    - Syenite 163
    - Gabbro 165
    - Diabase 168
  - Mining and milling operations 169
  - Composition of rutile concentrates 172
- General Electric Company's mine 173
  - General statement 173
  - Mining developments 175
  - Areal geology 176
    - Introduction 176
    - Syenite 179
      - Detailed description of occurrences 180
    - Nelsonite 184
      - Detailed description of occurrences 184
        - Composition of the apatite 189
        - Composition of the rutile 190
        - Composition of the ilmenite 190
    - Gabbro 191
    - Diabase 192
- The rutile ore 193
  - General statement 193
  - Syenite rutile 193
    - Megascopic character 193
    - Composition of the rutile 194
    - Microscopic character 195
  - Nelsonite rutile 196
    - Megascopic character 196
    - Composition of the rutile 197
    - Microscopic character 197

LOVINGSTON DISTRICT 198

- Introductory statement 198
  - Biotite gneiss 198
  - Amphibolite 199
  - Pegmatite and granite dikes 200
  - Nelsonite 201

GENERAL PETROLOGY OF THE AMHERST NELSON COUNTIES REGION 202

- Introduction 202
- Geologic occurrence 202
- Chemical characters 203
- Norms of Amherst-Nelson counties rocks 210
- Mineralogical characters 213
  - Introduction 213
    - Quartz 214
    - Feldspar 216
    - Pyroxene (hypersthene) 217

PAGE
Composition and optical properties.... 218
Amphibole (uralite).... 219
Composition and optical properties.... 219
Uralitization (alteration of hypersthene to uralite).... 220
Biotite.... 222
Olivine.... 222
Apatite.... 222
Magnetite.... 223
Ilmenite.... 223
Composition of the ilmenite.... 224
Rutile.... 226
The possible effect of vanadium on the color of rutile.... 228
Graphite.... 229
Other minerals.... 230
Textural characters.... 230
Age relations.... 230

MISCELLANEOUS MINERALS.... 231
Introductory statement.... 231
Minerals occurring within the mapped area not previously described.... 231
Sphalerite.... 231
Galena.... 232
Graphite.... 232
Kaolin.... 232
Minerals occurring beyond the limits of the mapped area.... 233
Allanite and sipylite.... 233
Cassiterite.... 233
Ferruginous conglomerate.... 234

GEOLOGY OF THE ORE-DEPOSITS OF THE ROANOKE COUNTY AREA.... 235
Location and topography.... 235
History and developments.... 236
Geology and petrography.... 236
General statement.... 236
Principal rock groups.... 237
Hypersthene-quartz syenite.... 237
General character.... 237
Microscopic character.... 238
Comparison with syenite of the northern Blue Ridge, Virginia.... 239
Pegmatite partly of unakite composition.... 240
Nelsonite.... 241
General statement.... 241
Megascopic character.... 241
Microscopic character.... 242
Individual description.... 243
Diabase.... 246
Genesis.... 246
Age.... 247

GEOLOGY OF THE ORE-DEPOSITS OF GOOCHLAND AND HANOVER COUNTIES.... 248
Location of rutile deposits.... 248
History.... 248
Topography.... 250
General geology and petrography.... 250
Introductory statement.... 250
Principal rock groups.... 251
Gneiss.... 251
Pegmatite.... 252

PAGE

- Diorite 253
- Diabase 254
- Pyroxenite 254
- The rutile ore 255
  - General character 255
    - Megascopic character 255
    - Microscopic character 255
    - Ilmenite 256
  - Mode of occurrence 256
  - Mineral associations 256
  - Genesis 257
  - Age of the deposits 258
- Economic considerations 258
  - Mining developments 258
    - Bowe farm 258
    - Nuckols farm 259
  - Commercial possibilities 260
    - Residual rutile 260
    - Pegmatite rutile 260
    - Conclusion 261

CHARLOTTE COUNTY AREA 262
- General statement 262
- Occurrence and character of rutile 262

BUCKINGHAM COUNTY AREA 264

ECONOMIC ASPECTS 265
- Future of rutile mining in Virginia 265
- Future development of rutile mining 267
- Future prospecting for apatite 268
- Future of apatite production 269

USES OF TITANIUM AND ITS COMPOUNDS 270
- General statement 270
- Metallic alloys 271
- Incandescent media 278
- Mordants and dyes 283
- Refractory coloring material in ceramics, etc 286
- Miscellaneous uses 287
- Methods of preparing titanium alloys 288
  - Ferro-titanium 288
  - Cupro-titanium 289

BIBLIOGRAPHY ON TITANIUM 290

INDEX 298

ILLUSTRATIONS

PLATE FACING PAGE

I. Map of rutile area in Amherst and Nelson Counties, Virginia . . in pocket

II. Piney River near Rose's Mill . . . . Frontispiece

III. Fig. 1. Photomicrograph of rutile-bearing pegmatite (?) from South Australia 36

Fig. 2. Photomicrograph of kragerite, a rutile-bearing aplite from Kragerö, Norway 36

Fig. 3. Photomicrograph of kragerite, a rutile-bearing aplite from Kragerö, Norway 36

IV. Fig. 1. Granite-gneiss overlain by mantle of residual rock decay 200 yards west of Lovingston 46

Fig. 2. Gulley cut in residual rock decay exposing complex structure along contact between syenite and gneiss 46

V. Fig. 1. Banded syenite-gneiss exhibiting pitted surface from differential weathering 47

Fig. 2. Detailed view of same exposure 47

VI. Fig. 1. Photomicrograph of biotite-quartz monzonite-gneiss near contact with syenite, .75 mile northeast of Roseland . . 63

Fig. 2. Photomicrograph of biotite-quartz monzonite-gneiss 1 mile north of A. G. Bryant's house 63

Fig. 3. Photomicrograph of biotite-quartz monzonite-gneiss 3 miles north of Lovingston 63

VII. Polished specimen of hornblende syenite from General Electric Company's mine, Nelson County 71

VIII. Fig. 1. Photomicrograph of feldspathic facies of syenite from General Electric Company's mine 73

Fig. 2. Photomicrograph of gabbro from W. A. Campbell's farm, Nelson County 73

Fig. 3. Photomicrograph of feldspathic facies of altered syenite from General Electric Company's mine 73

Fig. 4. Photomicrograph of feldspathic facies of altered syenite from American Rutile Company's quarries 73

IX. Fig. 1. Photomicrograph of rutile-bearing syenite, American Rutile Company's quarries 75

Fig. 2. Photomicrograph of quartz-rutile-bearing syenite, 0.5 mile southwest of Rose Union 75

Fig. 3. Photomicrograph of blue quartz in syenite filled with inclusions of rutile needles 75

X. Fig. 1. Photomicrograph of feldspathic facies of syenite, General Electric Company's mine 76

Fig. 2. Photomicrograph of feldspathic facies of syenite near entrance to Major Boyd's farm 76

Fig. 3. Photomicrograph of uralitized gabbro-gneiss 76

XI. Fig. 1. Contact between syenite and biotite-quartz monzonite-gneiss exposed in bed of Allen Creek 84

Fig. 2. Banded syenite-gneiss near contact between syenite and biotite-quartz monzonite-gneiss 84

PLATE FACING PAGE
XII. Fig. 1. Polished section of ilmenite nelsonite.................. 102
Fig. 2. Section of ilmenite nelsonite showing pitted surface from differential weathering.............................. 102
XIII. Fig. 1. Photomicrograph of ilmenite nelsonite, 0.25 mile northeast of Bryant................................... 113
Fig. 2. Photomicrograph of porphyritic ilmenite nelsonite, 0.75 mile northwest of Bryant.......................... 113
XIV. Nelsonite dike cut by a small fault........................ 116
XV. Polished specimen of rutile nelsonite showing banding......... 118
XVI. Fig. 1. Photomicrograph of rutile in syenite, American Rutile Company's quarries.............................. 119
Fig. 2. Photomicrograph of rutile in syenite, American Rutile Company's quarries.............................. 119
Fig. 3. Photomicrograph of rutile nelsonite, General Electric Company's mine.................................. 119
Fig. 4. Photomicrograph of rutile nelsonite, General Electric Company's mine.................................. 119
XVII. Fig. 1. Photomicrograph of magnetite nelsonite, 2 miles southwest of Lovingston...................................... 126
Fig. 2. Photomicrograph of fine-grained ilmenite nelsonite, 0.75 mile northeast of fig. 1.......................... 126
Fig. 3. Photomicrograph of intergrowth of ilmenite and quartz 126
XVIII. Section of mica schist on Dillard farm, 2 miles southwest of Lovingston.................................. 132
XIX. Fig. 1. Photomicrograph of hornblende nelsonite, 0.5 mile southeast of Lovingston.............................. 137
Fig. 2. Photomicrograph of hornblende nelsonite, 3 miles north of Lovingston.................................. 137
Fig. 3. Photomicrograph of hornblende nelsonite, 1.75 miles northwest of Lovingston.......................... 137
XX. Fig. 1. Photomicrograph of gabbro exposed in road at Roseland 139
Fig. 2. Photomicrograph of gabbro-nelsonite, 1.75 miles southwest of Bryant.................................. 139
Fig. 3. Photomicrograph of gabbro-nelsonite, 1.5 miles northeast of Rose's Mill.................................. 139
XXI. Fig. 1. Photomicrograph of gabbro-nelsonite, 1 mile south of Roseland 144
Fig. 2. Photomicrograph of gabbro-nelsonite, ⅝ mile south of Bryant 144
Fig. 3. Photomicrograph of gabbro-nelsonite, 0.25 mile northeast of Mr. Grant's house, Nelson County................ 144
XXII. Fig. 1. Outcrop showing contact between diabase dike and gabbro at Roseland...................................... 168
Fig. 2. Detailed view of same outcrop........................ 168
XXIII. Fig. 1. Diabase dike exposed in open cut on the American Rutile Company's property............................ 169
Fig. 2. Exposure of typical hornblende facies of syenite, American Rutile Company's quarries...................... 169

Plate		Facing Page
XXIV.	Fig. 1. Diabase dike cutting syenite in American Rutile Company's quarries	170
	Fig. 2. Outcrop of feldspathic facies of syenite, 0.5 mile north of Bryant	170
XXV.	Fig. 1. Mill and surface plant of the American Rutile Company at Roseland	171
	Fig. 2. View of Piney River valley with the Blue Ridge shown in the background	171
XXVI.	Fig. 1. General view of surface plant and quarries of the American Rutile Company	172
	Fig. 2. General view from the southeast showing lowland belt of rutile-bearing rocks in the foreground and the Blue Ridge beyond	172
XXVII.	Specimen of syenite containing much graphite	180
XXVIII.	Fig. 1. Photomicrograph of feldspathic facies of syenite containing graphite, General Electric Company's mine	181
	Fig. 2. Photomicrograph of mashed syenite containing garnet, General Electric Company's mine	181
	Fig. 3. Photomicrograph of gabbro-nelsonite, 1.5 miles west of Rose Union	181
XXIX.	Polished specimen of hornblende facies of syenite from the American Rutile Company's quarries at Roseland	183
XXX.	Polished section of rutile segregation in nelsonite dike from General Electric Company's mine	188
XXXI.	Polished section of a rutile segregation in nelsonite dike from General Electric Company's mine	188
XXXII.	Polished specimen of large Carlsbad twin of perthitic orthoclase in nelsonite dike	188
XXXIII.	Polished specimen of rutile-bearing syenite from outcrop on American Rutile Company's property across Tye River from their mill	194
XXXIV.	General view of Lovingston and valley taken from ridge northwest of the town	198
XXXV.	Fig. 1. Photomicrograph of fine-grained ilmenite nelsonite from Roanoke County	245
	Fig. 2. Photomicrograph of epidote-bearing ilmenite nelsonite from Roanoke County	245
	Fig. 3. Photomicrograph of epidote-bearing ilmenite nelsonite from Roanoke County	245
XXXVI.	Fig. 1. Polished section of a piece of rutile float, Bowe farm, near Goulden, Hanover County	252
	Fig. 2. Section of specimen showing intergrown quartz and rutile, Cox farm, Nelson County	252
XXXVII.	Fig. 1. Photomicrograph of cyanite with inclusions of rutile crystals from Charlotte County	264
	Fig. 2. Photomicrograph of cyanite altered to muscovite with inclusions of rutile crystals, from Charlotte County	264

ILLUSTRATIONS

FIGURE PAGE

1. Map of middle northeast Georgia, showing location of Graves Mountain in Lincoln County........ 23
2. Index map showing position of the rutile-ilmenite-apatite areas in Virginia........ 43
3. Topographic map of the Amherst-Nelson counties rutile area........ 45
4. Sketch of porphyritic gneiss exposed on south side of Tye River 1.5 miles north of Claypool........ 88
5. Map showing a part of the nelsonite bodies on the Giles farm 1 mile northwest of Roseland........ 115
6. Drill core from one of the borings in nelsonite on the Giles farm, 1 mile northwest of Roseland, showing contact between nelsonite and syenite........ 116
7. Section in open cut on the Dillard farm, 2 miles southwest of Lovingston, showing geologic relations of the rocks........ 131
8. Horizontal sections in shaft on the Dillard farm, 2 miles southwest of Lovingston........ 131
9. Vertical section in shaft on the Dillard farm, 2 miles southwest of Lovingston........ 132
10. Diagram showing variation in the molecular constituents of eight nelsonites from Nelson County........ 146
11. Topographic and geologic map of the American Rutile Company's property, Nelson County........ 162
12. Map of surface and underground workings of the General Electric Company's mine, showing outcrops of nelsonite dikes........ 174
13. Sketch in face of surface cut on dike No. 1, General Electric Company's mine, showing fingering out of nelsonite dike........ 177
14. Plans of adit and 100-foot levels, and vertical cross-section, in the General Electric Company's mine, Nelson County........ 178
15. Sketch showing alteration of pyroxene to amphibole (uralite)........ 183
16. Sketch showing nelsonite in face of southwest drive on No. 2 dike of the General Electric Company's mine, Nelson County........ 187
17. Sketch of granite dikes in biotite-quartz monzonite-gneiss on mountain slope 0.75 mile north of Lovingston, Nelson County........ 200
18. Diagram showing variation in the molecular constituents of the seven types of silicate rocks in the Amherst-Nelson counties area........ 208
19. Topographic map of a part of Roanoke County, showing location of nelsonite dikes 4 miles east of Roanoke City........ 235
20. Topographic map of a part of Goochland and Hanover counties, showing location of rutile areas........ 249
21. Sketch of pegmatite dike in Goochland County, showing relations to the inclosing granite-gneiss and mode of occurrence of rutile........ 253
22. Geologic map of the Charlotte County rutile area........ 263

LETTER OF TRANSMITTAL

Virginia Geological Survey,
University of Virginia,
Charlottesville, December 30, 1912.

To His Excellency, Hon. Wm. Hodges Mann, Governor of Virginia, and Chairman of the State Geological Commission.

Sir:—I have the honor to transmit herewith for publication, as Bulletin No. III-A of the Virginia Geological Survey Series of Reports, a report on "Geology of the Titanium and Apatite Deposits of Virginia," by Thomas Leonard Watson and Stephen Taber.

The report should prove of much economic value in directing attention to the extensive deposits of rutile—the principal ore of titanium—in the State, the only known ones of commercial value in the United States, and one of four thus far exploited in the world. It should also prove of much scientific interest because of the new rock types studied and described for the first time, with which the titanium and other ore minerals are associated, and their mode of occurrence.

Respectfully submitted,
Thomas L. Watson,
Director.

PREFACE

FIELD WORK.

The Amherst-Nelson counties area, which forms the main part of this report, began to attract attention about 1902, when the American Rutile Company's property at Roseland commenced producing rutile. In August, 1906, the senior writer with assistant Henry F. Day visited the area and devoted some days to a reconnaissance of the Roseland-Bryant portion of the district; and again in the spring of 1907 in company with Messrs. Hess and Spencer of the U. S. Geological Survey.

After the passage of the Legislative Act in March, 1908, reviving the Virginia Geological Survey, the senior writer in company with Joel H. Watkins as assistant began a general reconnaissance of the entire district preparatory to systematic study and mapping. Mr. Watkins spent the entire month of August and the early part of September in the district.

Systematic study was begun in the district early in June, 1909, when the junior writer as Assistant Geologist on the Virginia Geological Survey was assigned to the work of mapping the geology, and was occupied in this work from June to October. Several trips have been made into the district since September, 1909. Laboratory investigations and preparation of the report have been in progress since the late fall of 1909. Its delay is to be attributed in large measure to the senior writer, whose duties, as State Geologist, prevented his devoting consecutive time to its preparation.

SCOPE OF THE REPORT.

This report contains a discussion of the geology of titanium (rutile and ilmenite) and apatite deposits of Virginia, including (*a*) the Amherst-Nelson counties area, (*b*) the Roanoke County area, (*c*) the Goochland-Hanover counties area, and (*d*) the occurrence of rutile in Charlotte and Buckingham counties, which is of scientific interest but not of commercial importance.

The first chapter is devoted to a general discussion of *Titanium: Its History, Chemistry, Ores, Distribution and Occurrence.* Chapter II treats of the *Occurrence and Geographic Distribution of Rutile with Description of Areas.* It includes a discussion of rutile distribution in the United States, Canada, Norway, and South Australia, together with a description of each known locality that has produced some rutile.

The third chapter, entitled *Geology and Ore Deposits of the Amherst-Nelson Counties Region*, comprises an exhaustive study of the nature and distribution of individual rock-types and ores. This investigation, commenced some years ago, has resulted in much that is of scientific interest as well as of economic importance. The region is shown to be a comagmatic area of unusual scientific interest, many of the rock-types of which are new and described in detail for the first time. Economically two types of rutile as regards occurrence are fully discussed, in addition to ilmenite and apatite.

The fourth chapter, entitled *Geology and Ore Deposits of the Roanoke County Area,* deals in a similar manner with the ilmenite-apatite deposits (nelsonite) occurring four miles east of the city of Roanoke, and points out the similar and dissimilar features of its geology to that of the Amherst-Nelson counties area.

The fifth chapter discusses the Geology of the *Ore Deposits of Goochland and Hanover Counties,* in which have been recently found commercial deposits of rutile. In chapters VI and VII are given brief descriptions of the occurrence of rutile in Charlotte and Buckingham counties, in each of which the mineral is of scientific interest only.

The eighth chapter treats of *Economic Aspects,* including a discussion of the future of rutile and apatite mining in Virginia. Chapter IX discusses the *Uses of Titanium and Its Compounds,* and the volume closes with a *Bibliography on Titanium.*

ACKNOWLEDGMENTS.

It is a pleasure to acknowledge the many courtesies and kindly coöperation of the citizens residing within the several areas discussed in this report, but especially of Messrs. Slater and Wilson of the American Rutile Company, and Messrs. Vanderlip, Thayer, and Mathis, of the General Electric Company.

The writers are especially indebted to Mr. Frank L. Hess, of the U. S. Geological Survey, for many helpful suggestions and loan of material, including hand specimens, thin rock sections, photographs, etc., all of which he has freely and generously contributed throughout the progress of the work and for which grateful acknowledgment is made.

To Mr. Wm. M. Thornton, Jr., formerly chemist to the Virginia Geological Survey, the writers are indebted for the numerous complete and accurate analyses of the various rocks and minerals used in this report; to Dr. E. S. Larsen of the Federal Survey for examining and checking our results from the study of some of the thin sections of certain rocks from the Amherst-Nelson counties district; to Professor J. P. Iddings for kindly checking the norms of the different rocks; and to Mr. D. I. Bushnell, Jr., for the excellent photographs reproduced in Plates II, IV, V, XI, XII, fig. 2, XIV, XVIII, XXII, XXIII, XXV, XXVI, fig. 2, XXVII, XXXIV, and XXXVI, fig 2.

GEOLOGY OF THE TITANIUM AND APATITE DEPOSITS OF VIRGINIA

BY THOMAS LEONARD WATSON AND STEPHEN TABER.

TITANIUM: ITS HISTORY, CHEMISTRY, ORES, DISTRIBUTION AND OCCURRENCE.

HISTORY.[a]

Titanium was discovered in 1791[b] by McGregor while investigating a magnetic sand found in Menachan, Cornwall. He named the black sand menachanite (menaccanite) and the newly discovered element in the compound he called menachite. In 1794,[c] while engaged in the study of rutile, Klaproth announced the discovery of a new earth. To the metal of this earth he gave the name titanium in allusion to the "Titans," the fabled giants of ancient mythology. In 1797, Klaproth found that titanium was identical with menachite of McGregor, and the name titanium has been universally accepted.

CHEMISTRY.[d]

General properties.—Titanium belongs to the same chemical group of elements as silicon, zirconium, cerium, and thorium. It resembles these elements in being tetravalent, with a lower valence in some cases and, like zirconium, it is a weak base-forming or a weak acid-forming element. That it is isomorphous with zirconium and silicon in some compounds is shown in the table of titanium minerals given below on pages 10 and 11. In its behavior toward reagents titanium resembles somewhat closely niobium and tantalum, with which it is found associated in some compounds.

---

[a] Ohly, J., Analysis, Detection and Commercial Value of the Rare Metals, Denver, Col., 1907, 3d ed., p. 209.

Browning, P. E., Introduction to the Rarer Elements, New York, 1909, 2d ed., p. 96.

[b] Roscoe and Schorlemmer give the date as 1789; Treatise on Chemistry, 1900, vol. ii, p. 639.

[c] Roscoe and Schorlemmer give the date as 1795; Ibid., p. 639.

[d] Iddings, J. P., Igneous Rocks, 1909, vol. i, p. 60.

Hunter, M. A., Metallic Titanium, Jour. Amer. Chem. Soc., 1910, vol. xxxii, pp. 330-336.

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Browning, P. E., Introduction to the Rarer Elements, New York, 1909, p. 99 *et seq.*

Ohly, J., Analysis, Detection and Commercial Value of the Rare Metals, 1907, 3d ed., p. 208, *et seq.*

The atomic weight of titanium is 48.1. Elementary titanium has a high metallic lustre and in color resembles polished steel. It is hard and somewhat brittle when cold, but is malleable at a low, red heat, and may be readily forged like iron. As yet all attempts to draw the metal into wire have been unsuccessful. The specific gravity as determined by Moissan is 4.87, but working with titanium having a higher degree of purity Hunter determined it to be 4.50. Hunter[a] determined the melting point to be between 1,800° and 1,850° C.; a rod of the metal began to burn in air at a temperature of 1,200° C., the heat of oxidation being sufficient to melt the oxides formed. According to Moissan[b] titanium combines with oxygen at a temperature of 610°C. with incandescence.

Titanium is soluble in cold dilute sulphuric acid, hot concentrated hydrochloric acid, aquia regia, more slowly in nitric acid, and is attacked by dilute hydrofluoric and acetic acids. On heating titanium combines with the halogens and oxygen with incandescence to form halogen and oxygen salts, and with sulphur and carbon to form sulphides and carbide. It combines with nitrogen with extreme readiness to form nitrides.

Methods of preparation.—Prior to the work of Hunter in 1900, pure metallic titanium had probably not been prepared. Perhaps the nearest approach to it was obtained by Moissan in the electric furnace, the product of which contained 2 per cent of carbon. Elementary titanium may be prepared (1) by reduction of the titanofluorides by the alkali metals, (2) by reduction of titanium dioxide by carbon, and (3) by reduction of titanium tetrachloride with sodium. According to Hunter moderately large quantities of pure titanium can be prepared with ease by the last method. A general review of the methods used in the preparation of the metal follows in summary.

The difficulties involved in the production of pure metallic titanium are due to its high fusion point and strong affinity for nitrogen and carbon, as well as for oxygen. The early attempts at the reduction of the metal from its compounds usually resulted in the production of some of the nitrides or carbides, which because of their high metallic lustre were often mistaken for the metal. Among the early investigators in this field may be mentioned Wollaston,[c] Berzelius,[d] Rose,[e] Wöhler,[f] and Deville.[g]

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[a] Hunter, M. A., Metallic Titanium, Jour. Amer. Chem. Soc., 1910, vol. xxxii, pp. 330-336; Rensselaer Poly. Inst., Eng. and Sci. Series No., 1, Feb. 1, 1911.

[b] Moissan, Henri, Traité de Chimie Minérale, Tome II, p. 494.

[c] Phil. Trans., 1823, vol. 17.

[d] Pogg. Ann., 1825, vol. 4, p. 3.

[e] Pogg. Ann., 1837, vol. 16, p. 57.

[f] Compt. Rend., 1849, vol. 29, p. 505.

[g] Compt. Rend., 1857, vol. 45, p. 480.

Nilson and Petersson[a] attempted to prepare metallic titanium by reducing titanium tetrachloride ($TiCl_4$) with sodium in an air-tight cylinder of solid steel. The best results obtained by them was a product containing about 94.73 per cent titanium, the chief impurity being oxygen; and as this was supposed to be present as titanium monoxide (TiO), the material produced would contain only 78.92 per cent of metallic titanium.

Moissan[b] succeeded in reducing titanium dioxide (TiO_2) with carbon in a lime or magnesia crucible and obtained under the heat of a powerful electric arc a product that contained 5 per cent carbon. By reheating this with additional titanium dioxide the amount of carbon was reduced to 2 per cent, but as it was probably present in the form of carbide of titanium and as the material must have contained some oxygen it was far from being pure metallic titanium. Better results are said to be obtained when the reduction takes place simultaneously with the oxide of another metal with which the titanium may form an alloy.

The reducing power of metallic aluminum has been used in the preparation of titanium from rutile by both the Goldschmidt and the Rossi processes (see page 288). Kuhne[c] has proposed a modification of the Goldschmidt process by which a peroxide, such as barium or sodium, is introduced into the mixture to increase the rate of the reaction and raise the temperature to a higher point. More aluminum must be used in this case than in the aluminothermic reaction, as there must be sufficient to combine with the oxygen of the peroxide as well as with that of the rutile.

An electrolytic process has been employed by Huppertz[d] to obtain pure metallic titanium. Calcium chloride was used as the electrolyte and the titanium oxide reduced cathodically by the calcium ion, the cell used being a strontium metallic furnace. The metal obtained by this process is said to be absolutely free from nitrogen and carbon and has a perfect metallic lustre with a brilliant white color.

Recently Hunter,[e] in an attempt to reduce sodium titanofluoride (Na_2TiF_6) with metallic potassium in an iron cylinder, obtained a product containing 73.2 per cent of titanium. Potassium and barium titanofluorides were tried with no better success. He also repeated Moissan's method, but his best results gave a carbon content of 4.6 per cent. Later, by using the method of Nilson and Petersson and exercising extraordinary care to exclude air from the apparatus, Hunter succeeded in producing metallic titanium practically free from impurities.

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[a] Z. physik. Chem., 1887, vol. 1, p. 25.

[b] Compt. Rend., 1895, vol. 120, p. 290.

[c] Kuhne, K. A., Electrochemical and Metallurgical Industry, 1909, vol. vii, p. 127.

[d] Huppertz, W., Electrochemical and Metallurgical Industry, 1905, vol. iii, p. 35; Metallurgie Nos. 17, 18, 19, 21, and 22, 1904.

[e] Hunter, M. A., Metallic Titanium, Jour. Amer. Chem. Soc., 1910, vol. xxxii, pp. 330-336; Rensselaer Poly. Inst., Eng. and Sci. Series No. 1, Feb. 1, 1911.

The titanium tetrachloride used was prepared by chlorination of titanium carbide, the chloride formed being refluxed in a current of nitrogen to remove chlorine and then repeatedly distilled with the rejection of end fractions. The fraction boiling between 136° and 137° was shaken repeatedly with mercury and sodium amalgam, and redistilled to give a water white product boiling at constant temperature.

The reaction was carried out in a steel bomb, capable of withstanding a total internal pressure of 80,000 pounds, and having a capacity sufficient to accommodate 500 grams of titanium tetrachloride and the 245 grams of sodium theoretically required for the reduction. The bomb with its charge was brought to a low, red heat, then cooled and its contents leached with water, the residue consisting of metallic titanium, partly in the form of a fine gray powder and partly in small metallic beads. The reaction inside the bomb is supposed to be almost instantaneous and the heat of the reaction is sufficient to melt part of the titanium into small beads. Two analyses of these beads gave, respectively, 99.9 and 100.2 per cent titanium, and no trace of iron or sodium could be found. The amount of titanium produced by this method was 90 per cent of the metal that theoretically should have been obtained from the titanium tetrachloride placed in the bomb.

COMPOUNDS OF TITANIUM.

According to Browning[a] the following are typical compounds of titanium: Oxides, TiO, Ti_3O_4, Ti_2O_3, Ti_7O_{12}, TiO_2, Ti_2O_5, TiO_3; hydroxides, $Ti(OH)_4$, $Ti(OH)_6$; chlorides, $TiCl_3$, $TiCl_4$; bromide, $TiBr_4$; iodide, TiI_4; fluoride, TiF_4; titanofluorides, R_2TiF_6, etc.; sulphides, Ti_2S_3, TiS_2; sulphates, $Ti_2(SO_4)_3$, $Ti(SO_4)_2$; nitrides, Ti_3N_4, Ti_5N_6, TiN_2; carbide, TiC; silicide, $TiSi$; titanates, $RTiO_3$, R_2TiO_3; acids (see hydroxides), H_2TiO_3.

For the methods of separation of titanium and the preparation of its salts, and its detection and estimation in materials, the reader is referred to the standard text-books and treatises on chemistry. The methods by which elementary metallic titanium may be obtained are given on pages 2 to 4.

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[a] Browning, P. E., Introduction to the Rarer Elements, New York, 2d ed., 1909, p. 99.

MINERALOGICAL FORMS OF TITANIUM.

Titanium is a characteristic constituent of certain pyrogenetic compounds. It enters as an element into the composition of many minerals but very rarely in considerable quantity in any one locality. It occurs in a variety of mineralogical forms, chiefly as oxides, titanates, and silicotitanates; in many silicates, and in some niobates and tantalates. Titanium occurs as oxide (rutile chiefly) in some rock magmas rich in silicon and relatively poor in the base-forming elements; as titanates it combines with calcium and silicon in most rock magmas in which there is sufficient calcium and titanium to form calcium titanate (perovskite), and in magmas lowest in silicon and richest in iron it combines with ferrous iron to form iron titanate (ilmenite); and as silicates it either replaces silicon in the acid radical or enters as a weak base-element.[a]

Titanium is frequently present in iron ferrate (magnetite) and ferric oxide (hematite) in variable amounts. It is frequently present in small amounts in biotite, amphiboles, augite, certain species of garnet, and in some other silicate minerals. It has been found[b] in some mineral waters, in some varieties of coal, in meteorites, and has been detected in the sun's atmosphere by means of the spectroscope. It has been found in the ash of certain varieties of wood, in cowpeas, and cotton-seed meal, and in the bones of animals.

TITANIUM ORES.

The commercial source of titanium is entirely limited to the titanium ores, of which there are only three at present, namely, rutile, ilmenite, and titanium-rich magnetite. Many of the titaniferous magnetites are too low in titanium to be of commercial value. Although titanium is rather widely distributed in a variety of mineralogical forms the only three that occur in nature in sufficient quantity to be of commercial value are the oxide (rutile), the titanate (ilmenite), and the titanium-rich iron ferrate (titaniferous magnetite). Many other forms of titanium occur but they are either too rare or complex in composition, or are not found in sufficient quantity to be of value, and are interesting chiefly on account of their chemical and mineralogical characters. Titaniferous magnetites occur in large quantity at a number of localities but they are variable in composition, ranging from a fraction of 1 per cent to more than 20 per cent of TiO_2. Most of the ferrotitanium manufactured at present is made either from titanium-rich magnetite or ilmenite, chiefly because they are cheaper than rutile. Both rutile and ilmenite occur in Virginia in sufficient quantity to be of commercial value, and while titaniferous magnetites are found in the crystalline region of the State their extent and composition are imperfectly known.

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[a] Iddings, J. P., Igneous Rocks, New York, 1909, vol. i, pp. 60, 64, 145.

[b] Baskerville, Chas., On the Universal Distribution of Titanium, Jour. Amer. Chem. Soc., 1899, vol. xxi, p. 1099.

Browning, P. E., Introduction to the Rarer Elements, New York, 1909, 2d ed., p. 97.

The general properties (physical and chemical) and occurrence of rutile, ilmenite, and titanium-rich magnetite are briefly described below. The properties, relationships, associations, and mode of occurrence of rutile and ilmenite as found in the Virginia areas form the basis of this report. The titaniferous magnetites are not considered in this report but will be included in a forthcoming bulletin by the State Geological Survey on the iron ores of Virginia.

OXIDES.

There are many oxides of titanium occurring in nature but only one of them, rutile, is important as an ore.

Rutile.—Rutile crystallizes in the tetragonal system commonly in prismatic crystals vertically striated or furrowed; often slender acicular. It is also compact, massive to coarse and fine granular. Twinning is frequent and of several kinds. Cleavage distinct; fracture subconchoidal to uneven. Brittle. Hardness 6 to 6.5. Specific gravity 4.18 to 4.25; also to 5.2 in a black variety containing 10 per cent FeO. Lustre, metallic-adamantine. Color reddish-brown, passing into red; sometimes yellowish, bluish, violet, black, rarely grass-green. Streak pale brown. Transparent to opaque.

The chemical composition of rutile when pure is TiO_2 corresponding to oxygen 40 per cent, titanium 60 per cent. A little iron and vanadium are usually present, the former ranging up to 10 per cent; less often a little chromium and tin. Rutile is insoluble in acids, and infusible before the blowpipe. Molecular weight, 80.1; molecular volume, 19.1.

Rutile occurs in igneous, metamorphic, and sedimentary rocks. In igneous rocks it occurs both as a pyrogenetic constituent and as an alteration product. It is common in the metamorphic rocks, such as gneisses, mica-schists, amphibolites, and phyllites, and sometimes in granular limestone and dolomite.[a] It also occurs in some sedimentary rocks, in some rocks produced by contact metamorphism, and in veins both metalliferous and nonmetalliferous.[a] According to Emmons[b] rutile is formed in igneous rocks, in pegmatite dikes, in contact metamorphic deposits, in deposits of the deep vein zone, and as a product of dynamo-regional metamorphism.

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[a] Iddings, J. P., Rock Minerals, New York, 1906, p. 498.

Rutile is formed as a secondary mineral, derived from ilmenite and titanite, and sometimes from certain ones of the ferromagnesian silicates, especially biotite. It is relatively a very stable mineral, but sometimes alters to leucoxene and is sometimes accompanied by the formation of ilmenite.

TITANATES.

Of the many forms of titanates only one, ilmenite, is important as an ore.

Ilmenite.—Ilmenite is a heavy, black mineral crystallizing in the hexagonal system. It is rarely seen in good megascopic crystals in rocks, but usually occurs in embedded grains and masses, sometimes in plates of irregular to hexagonal outline, and loose as sand. Cleavage not developed. Fracture conchoidal; brittle. Color iron-black, sometimes with faint reddish to brownish tinge; lustre metallic to submetallic; streak black to brownish-red. Opaque. Hardness 5 to 6; specific gravity 4.5 to 5. Slightly magnetic, but variable.

The chemical composition of ilmenite is variable. If normal the mineral is expressed by the formula $FeO.TiO_2$, corresponding to FeO, 47.3 per cent, TiO_2, 52.7 per cent. There is an isomorphous series $(Fe,Ti)_2O_3$ with variable amounts of iron and titanium grading to hematite. Sometimes contains magnesium replacing ferrous iron. Many analyses of ilmenite do not correspond to the formula given above, but approximate more closely to the one suggested by Rammelsberg, $FeO.TiO_2.nFe_2O_3$. (See pages 223-226 for a discussion of the Virginia ilmenite.) Recent studies of ilmenite from some localities suggest that the ferric oxide present in the mineral is not in chemical combination, but is mechanically admixed as inclusions or intergrowths of hematite. Very difficultly fusible before the blowpipe; becomes magnetic in the reducing flame. Fused with sodium carbonate, dissolved in hydrochloric acid, and the solution boiled with tin becomes violet, showing titanium. Difficultly soluble in acids; decomposed by fusion with bisulphate of potash. Molecular weight, 152; molecular volume, 30.4.

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[a] Winchell, N. H. and A. N., Elements of Optical Mineralogy, New York, 1909, p. 347.

[b] Emmons, W. H., A Genetic Classification of Minerals, Econ. Geology, 1908, vol. iii, p. 621.

Ilmenite is a widely distributed mineral, occurring as a common constituent in igneous rocks from granite to gabbro and related rocks and their lava forms. It occurs in these rocks in the same manner as magnetite which it often accompanies. It is similarly found in many metamorphic rocks, especially gneiss, mica-schist, and amphibolite. According to Lindgren[a] and Emmons[b] ilmenite is formed in igneous rocks, in pegmatites, in contact metamorphic deposits under regional metamorphic conditions, and in deep veins. Ilmenite in rocks closely resembles hematite and magnetite, and unless the grains are of such size that they can be safely tested, the discrimination of these minerals in rock sections is not always possible. The most important occurrences of ilmenite are in the coarser grained gabbros and anorthosites where the mineral is very common, and is not infrequently segregated in places into large masses.

Inmenite in rocks commonly alters to a whitish, yellowish, or brownish aggregate, which is highly refracting and when transparent highly double refracting, usually called leucoxene, sometimes titanite. It alters sometimes to carbonate with the separation of rutile, a change which appears to be confined to certain phyllites.

FERRATES.

Magnetite.—Magnetite crystallizes in the isometric system, most commonly in octahedrons, also in dodecahedrons, and in a combination of both. It is also noted in rocks as irregular, formless grains of variable size and at times forms large masses. Cleavage is not distinct, but octahedral parting is often highly developed. Fracture uneven; brittle. Streak, black; opaque. Color iron-black; lustre metallic; strongly magnetic, sometimes showing polarity. Hardness 5.5 to 6.5; specific gravity 5.2.

Magnetite corresponds in chemical composition to $FeO.Fe_2O_3$, containing FeO, 3.10 per cent, and Fe_2O_3, 69.0 per cent. In many localities the mineral contains TiO_2 (titaniferous magnetite) ranging in amount up to 20 per cent. Only the titanium-rich magnetites are important in this connection. The titanium in the magnetite of several localities has been shown recently to be present in the form of ilmenite mechanically admixed with the magnetite as inclusions or intergrowths. Difficultly fusible before the blowpipe, becoming nonmagnetic in the oxidizing flame; slowly soluble in hydrochloric acid. Molecular weight 230.32; molecular volume 44.515.

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[a] Lindgren, W., The Relation of Ore-Deposition to Physical Conditions, Econ. Geology, 1907, vol. ii, p. 125.

[b] Emmons, W. H., A Genetic Classification of Minerals, Econ. Geology, 1908, vol. iii, p. 621 *et seq.*

Magnetite is one of the most widely distributed of minerals. It occurs as a pyrogenetic mineral in all kinds of igneous rocks, ranging from scant disseminations of small grains and crystals of microscopic dimensions to segregated masses of considerable size. It is found similarly in the crystalline schists, and in many of its occurrences magnetite is often intimately associated with ilmenite. Large bodies of titaniferous magnetite, associated usually with gabbroic rocks and regarded as magmatic segregation deposits, occur in the Adirondacks region of New York, in Canada, and in northern Europe.

According to Emmons[a] magnetite is formed in igneous rocks, in pegmatite dikes, in contact metamorphic deposits, in the deep vein zone, as a product of dynamo-regional metamorphism, and as a secondary mineral in zones of oxide and sulphide enrichments. Magnetite alters, according to Van Hise,[b] into hematite, limonite, and siderite; the changes taking place with the expansion of volume, liberation of heat, and decrease in symmetry.

TABLE OF TITANIUM MINERALS.

The titanium minerals listed below have been recognized in nature and described.

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[a] Emmons, W. H., A Genetic Classification of Minerals, Econ. Geology, 1908, vol. iii, p. 620.

[b] Van Hise, C. R., A Treatise on Metamorphism, Mon. xlvii, U. S. Geol. Survey, 1904, p. 229.

Titanium Minerals.[a]

Mineral	Composition	Contains TiO_2
		Per cent.
Oxides:		
Rutile[b]	TiO_2	100
Octahedrite (anatase)	TiO_2	100
Brookite[b]	TiO_2	100
Titano-magnetite	Magnetite (Fe_3O_4) with variable TiO_2	Variable up to 25
Titanates:		
Ilmenite[b]	$FeTiO_3$	52.7
Pyrophanite	$MnTiO_3$	53.1
Geikielite	$MgTiO_3$	67.7
Perovskite	$CaTiO_3$	58.9
Pseudobrookite	$Fe_4(TiO_4)_3$	42.9
Arizonite	$Fe_2O_3.3TiO_2$ or $Fe_2Ti_3O_9$	58.8
Knopite	$RO.TiO_2$. Closely related to perovskite but contains cerium	54.1–58.7
Iserite	$FeTi_2O_5$	69.5
Titano-silicates:		
Titanite[b]	$CaTiSiO_5$	40.8
Schorlomite	$3CaO.(Fe,Ti)_2O_3.3(Si,Ti)O_2$	12.5–22.1
Keilhauite	$15CaTiSiO_5.(Al,Fe,Y)_2(Si,Ti)O_5$	26.7–36.6
Guarinite	$CaTiSiO_5$	40.8
Tscheffkinite	Related to keilhauite but uncertain	16.1–21.2
Astrophyllite	$(Na,K)_4(Fe,Mn)_4Ti(SiO_4)_4$	7.1–13.6
Aenigmatite	$2Na_2O.9FeO.AlFeO_3.12(Si,Ti)O_2$	5.6
Cossyrite	Similar to aenigmatite	Undetermined
Yttrotitanite	See keilhauite	See keilhauite
Lamprophyllite	Related to astrophyllite	Undetermined
Neptunite	$\dot{R}_2\ddot{R}TiSi_4O_{12}$	18.1
Johnstrupite	A complex silicate of the cerium metals, Ca and Na chiefly, with Ti and F	7.6
Mosandrite	Very near Johnstrupite	5.3–9.9
Rinkite	Near Johnstrupite and mosandrite	13.4
Ivaarite	Similar to schorlomite	18.98
Carlosite	Same as neptunite	18.1
Benitoite	$BaTiSi_3O_9$	19.3
Lorenzenite	$Na_2(TiO_2)Si_2O_7$	35.2
Yttrocrasite	A hydrous titanate of the yttrium earths and thorium	49.7
Delorenzite	$2FeO.UO_2.2Y_2O_3.24TiO_2$(?)	68.9
Davidite	TiO_2 with Fe, U, V, Cr, and rare earths	50.0+
Narsarsukite	Acid titano-silicate of ferric iron and sodium	14.0
Niobates and Tantalates:		
Pyrochlore	$RNb_2O_6.R(Ti,Th)O_3.NaF$	5.4–13.6
Aeschynite	$\ddot{R}_2Nb_4O_{13}.\ddot{R}_2(Ti,Th)_5O_{13}$	21.2
Polymignite	$R((Nb,Ta)O_3)_3.5\ddot{R}((Ti,Zr)O_3)_3$	18.9

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[a] Compiled from Dana, E. S., A System of Mineralogy: Hintze, C., Handbuch der Mineralogie; and other sources.

[b] Varieties omitted.

Titanium Minerals (Continued).

Mineral	Composition	Contains TiO_2
Niobates and Tantalates:		*Per cent.*
Euxenite	$\ddot{R}(NbO_3)_3.\ddot{R}_2(TiO_3)_3.\frac{3}{2}H_2O$	20.0-23.5
Polycrase	$\ddot{R}(NbO_3)_3.2\ddot{R}_2(TiO_3)_3.3H_2O$	25.2-29.3
Blomstrandite	A niobate, tantalate, and titanate of uranium	10.7
Dysanalyte	$6RTiO_3.RNb_2O_6$	40.6–59.3
Strüverite	$FeO(Ta,Cb)_2O_5.6TiO_2$ (?)	44.0
Epistolite	$Nb_2O_5.SiO_2.TiO_2.Na_2O.H_2O$(?)	7.2
Blomstrandine-Priorite	Niobates and titanates of Y, Er, Ce, and U	21.9–32.9
Marignacite	Same as pyrochlore	2.9
Ilmenorutile	$FeO.Nb_2O_5.5TiO_2$	53.0–73.8
Silicates:		
Amphibole	$CaR_3(SiO_3)_4$. Variable amounts of TiO_2	As much as 8.5
Pyroxene	$CaR(SiO_3)_2$. Variable amounts of TiO_2	As much as 4.6
Biotite	$(H,K)_2(Mg,Fe)_4(Al,Fe)_2(SiO_4)_4$. Variable amounts of TiO_2	Variable up to 4.7
Lepidomelane	Iron mica, with variable amounts of TiO_2	Variable up to 4.7
Rosenbuschite	$6CaSiO_3.2Na_2ZrO_2F_2.(TiSiO_3.TiO_3)$	6.9–7.6
Titanolivine	Olivine $(Mg,Fe)_2SiO_4$ with variable TiO_2	3.5–6.1
Andradite	$Ca_3Fe_2(SiO_4)_3$; also $Ca_3Fe_2((Si,Ti)O_4)_3$ with variable TiO_2	Variable up to 10.8
Leucosphenite	$Na,Ba(TiO_2)(Si_2O_5)_5$	13.2
Rhönite	$(Ca,Na_2,K_2)_3Mg_4\ddot{Fe}_2\dddot{Fe}_3Al_4(Si,Ti)_6O_{30}$	9.5
Miscellaneous:		
Hydrotitanite	Altered form of dysanalyte	82.8
Warwickite	Perhaps $6MgO.FeO.2TiO_2.3B_2O_3$	23.5
Zirkelite	$(Ca,Fe)O.2(Zr,Ti,Th)O_2$	14.95
Derbylite	$6FeO.5TiO_2.Sb_2O_5$	34.6
Lewisite	$5CaO.2TiO_2.3Sb_2O_5$	11.7
Mauzeliite	$4(Ca,Pb)O.TiO_2.2Sb_2O_5$	7.9
Hainite	Composition doubtful, probably allied to mosandrite	Undetermined
Senaite	$(Fe,Pb)O.2(Ti,Mn)O_2$. Uncertain	57.2

Of the large number of titanium-bearing minerals enumerated in the table above, most of them are rare, and are only of scientific interest. The largest concentrations of titanium are as oxide (rutile), iron titanate (ilmenite), and iron ferrate (magnetite). At present rutile (titanium dioxide) is the principal source, commercially, of titanium.

In the Virginia areas titanium occurs as concentrations of commercial grade and quantity in two mineralogical forms, dioxide (rutile) and iron titanate (ilmenite). Titanium also occurs in the same localities in different mineralogical form as an alteration product (leucoxene) derived from both rutile and ilmenite, and as an original iron ferrate (magnetite), and occasionally as a pyrogenetic mineral (titanite) in the rutile-bearing rocks.

DISTRIBUTION AND OCCURRENCE OF TITANIUM.

Titanium-bearing minerals, of which there are many (see pages 10-11), occur in a variety of associations, are widely distributed, and in such quantities as to make titanium a relatively abundant element. Clarke's[a] estimate of titanium, in 1891, in the solid crust of the earth, was 0.33 per cent, equivalent as oxide to 0.55 per cent. In 1900, he revised his estimate increasing the amount of titanium to 0.41 per cent, equivalent as oxide to 0.60 per cent, giving titanium ninth place in the scale of abundance and standing next to potassium.[b] Van Hise[c] gives the amount of titanium in 78 shales as 0.65 per cent, in 624 sandstones as 0.33 per cent, and in 843 limestones as 0.07 per cent. He says: "It thus appears that as compared with the original rocks the amount of titanium is somewhat increased in the shales, is reduced to a little more than one-half in the sandstones, and is less than one-eighth in the limestones" (p. 975). Estimating the amount of titanium in the original igneous rocks by that in the sedimentary rocks, Van Hise obtains 0.525 per cent which, as he states, accords well with the actual amount estimated by analyses in the original igneous rocks, 0.55 to 0.60 per cent (p. 975). Dunnington[d] has shown the widespread distribution of titanium in soils and clays. Rutile is usually assumed to be the form in which the titanium occurs in clays. It may be seen under the microscope in many fire clays, and analyses sometimes show the presence of TiO_2 to the extent of 2 per cent.[a] In some of the bauxitic clays of Georgia,[b] TiO_2 exceeds 9 per cent.

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[a] Clarke, F. W., Bull. No. 78, U. S. Geol. Survey, 1891, p. 39.

[b] Clarke, F. W., Bull. No. 168, U. S. Geol. Survey, 1900, p. 15.

[c] Van Hise, C. R., A Treatise on Metamorphism, Mon. xlvii, U. S. Geol. Survey, 1904, pp. 974-975.

[d] Dunnington, F. P., Distribution of Titanic Oxide upon the Surface of the Earth, Amer. Jour. Sci., 1891 (3d ser.), vol. 42, pp. 491-495.

Titanium is not the rare element that it was formerly considered. It is almost invariably present in igneous rocks, usually in very small amounts, and in the sediments derived from them. It occurs in largest amounts in rocks lowest in silicon and richest in iron. Except silicon, titanium is a commoner element in igneous rocks than either of the other members of the titanium group. Out of 800 igneous rocks analyzed in the laboratory of the United States Geological Survey, 784 contained titanium.[c] Concerning its occurrence in igneous rocks Washington says:[d]

> "It (titanium) is much more abundant in basic than in acid rocks, and its affinities in the magma seem to be decidedly rather with iron than with magnesium, and still less with lime. While it is not commonly associated with alkalic rocks, yet when these are low in silicon, it shows a tendency to be present in considerable amount when the rock is sodic, as indicated by recent rock analyses; and this tendency to association of titanium with sodium appears mineralogically, as in the soda amphiboles, some of which are highly titaniferous, and in certain rare minerals, astrophyllite and rosenbuschite. Highly potassic and highly calcic rocks seldom show large amounts of titanium, though most of the mineral titanates contain calcium as the base."

Mineralogically, the commonest occurrences[e] of titanium in rocks are as titanite, ilmenite, rutile, and perovskite. Titanium is often concentrated in beds of titanic iron ore.

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[a] Ries, H., Clays, New York, 1908, 2d ed., p. 58.

[b] Watson, Thomas L., Bauxite Deposits of Georgia, Bull. No. 11, Ga. Geol. Survey, 1904.

[c] Clarke, F. W., The Data of Geochemistry, Bull. 491, U. S. Geol. Survey, 1911, p. 20.

[d] Washington, H. S., The Distribution of Elements in Igneous Rocks, Trans. Amer. Inst. Mng. Engrs., 1909, vol. xxxix, p. 755.

[e] Clarke, F. W., Loc. cit., p. 20.

OCCURRENCE AND GEOGRAPHIC DISTRIBUTION OF RUTILE WITH DESCRIPTION OF AREAS

MODE OF OCCURRENCE.

GENERAL STATEMENT.

Rutile occurs in all varieties of rocks, igneous, metamorphic, and sedimentary, commonly as short, stout, and elongated prisms frequently showing striations on the prism faces, as acicular hairlike forms, and as formless grains and masses of variable size. Many of its occurrences in rocks are of microscopic proportions, chiefly as inclusions in the rock-forming silicate minerals. Less often it occurs in granular masses sufficiently concentrated to be of commercial importance. It is frequently observed in hairlike crystals penetrating quartz, and sometimes as reticulated platelike masses of elongated crystals referred to as sagenite.

Rutile is a pyrogenetic constituent of igneous rocks, and according to Van Hise[a] "has widespread occurrence in clastic and metamorphic rocks, both as an allogenic and as an autogenic constituent, in the latter case generally being derived from ilmenite." It may be derived from brookite, ilmenite, octahedrite, and titanite.

Classified genetically rutile is formed as a product of (1) igneous rocks —crystallization from magma, (2) pegmatite dikes, (3) contact metamorphic deposits, (4) the deep, middle, and upper vein zones, and (5) dynamo-regional metamorphism.[b] Lindgren[c] classified rutile as one of the "persistent minerals" (persistent from igneous conditions to near the surface), and he lists the mineral as being formed under igneous conditions, pegmatitic conditions, contact metamorphic conditions, deeper vein zone, and middle and upper vein zone.

Of the several occurrences listed above (1) and (2), and rarely (3) and (5), constitute the principal sources of rutile.

ROCK ASSOCIATIONS.

Igneous rocks.—Rutile has been observed in most of the principal types of igneous rocks, commonly as an accessory constituent, including rocks of acid, basic, and intermediate composition. Its grains and crystals are usually of microscopic size, though not uncommonly of macroscopic dimensions. It occurs in intrusive or plutonic igneous rocks, such as granite, syenite, and gabbro; and in effusive or volcanic rocks, such as andesite of Pachuca, Mexico, Assuk, Greenland, and Pack Saddle Island, Cape Horn.[a]

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[a] Van Hise, C. R., A Treatise on Metamorphism, Mon. xlvii, U. S. Geol. Survey, 1904. p. 230.

[b] Lindgren, W., The Relation of Ore-Deposition to Physical Conditions, Econ. Geology, 1907, vol. ii, pp. 108, 123. 125.
Emmons, W. H., A Genetic Classification of Minerals, Econ. Geology, 1908, vol. iii, pp. 621, 625.
Van Hise, C. R., Loc. cit, 1904, p. 230, etc.

[c] Lindgren, W., Loc. cit., pp. 108, 123, 125.

Most of the known larger deposits of rutile that are of commercial importance are associated with gabbro (including anorthosite), chiefly as magmatic differentiation deposits. Occurrences of this type include those of the Amherst-Nelson counties area in Virginia, which in major part form the subject of this report (pages 42-234), the Bay St. Paul area in Quebec, Canada (pages 31-33), and the Kragerö area in southern Norway as aplite cutting gabbro (pages 37-41). A second important and new occurrence of rutile is found in the Amherst-Nelson counties area, Virginia, as dikelike bodies of an even-granular, ultrabasic igneous rock (nelsonite[b]) composed essentially of the ore minerals ilmenite and apatite with sometimes rutile as the dominant mineral (pages 100-155).

Rutile sometimes occurs in igneous rocks in hairlike crystals penetrating the rock-forming minerals, such as quartz in granite, etc., and in long needles penetrating andesite from the localities mentioned above.

Sedimentary rocks.—Because of its resistance to atmospheric agencies rutile is a frequent mineral in beds of sand and gravel, and in the residual decay derived from the weathering of crystalline rocks in which it originally occurred. It is common as grains in many gold-bearing sands and gravels, in the monazite sands of the Carolinas, and in similar sands composed of heavy resistant minerals from various localities. In the investigation of the black sands of the Pacific slope,[c] by the U. S. Geological Survey, rutile was reported as a minor constituent in the sands of some localities.

Metamorphic rocks.—Rutile has been reported as occurring in most classes of metamorphic crystalline rocks. It is described as being of common occurrence in gneiss, mica schist, phyllites, and sometimes in granular limestone and dolomite.[d] Clarke[e] quotes A. Bergeat on the observation of rutile, ilmenite, and titanite, which had formed as a single generation and crystallized before the rutile, in a hornblende gneiss from Freiberg. As a secondary product rutile is common in many slates in the form of microlites.

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[a] Iddings, J. P., Rock Minerals, New York, 1906, p. 498.

[b] Watson, Thomas L., Mineral Resources of Virginia, 1907, p. 300.
Watson, Thomas L., and Taber, S., The Virginia Rutile Deposits, Bull. 430, U. S. Geol. Survey, 1909, Part I, pp. 206-207.

[c] Mineral Resources of the United States, Calendar Year, 1905, pp. 1175-1258.

[d] Dana, E. S., A System of Mineralogy, 1900, p. 239.
Clarke, F. W., Bull. No. 330, U. S. Geol. Survey, 1908, p. 290.
Iddings, J. P., Op. cit., 1906, p. 498.

[e] Clarke, F. W., Op. cit., p. 290.

In addition to the types of metamorphic rocks mentioned above, rutile is a frequent constituent of some quartzites, especially some of the Piedmont quartzites of Georgia,[a] the Carolinas, and Virginia.[b] Of the occurrences of rutile in the Piedmont quartzites, the most noteworthy one is Graves Mountain, Lincoln County, Georgia, where rutile is found with an interesting association of rather uncommon minerals (see pages 23-27).

Other forms of occurrence, veins, pegmatites, etc.—In Norway and Sweden rutile is reported as an important constituent at times in apatite veins which, according to Vogt,[c] are of pneumatolytic character connected with gabbro, and were formed soon after the rock. The mineral is so abundant in some of the veins as to be mined, and is associated with other titanium minerals, ilmenite and titanite. Lindgren[d] remarks that rutile and anatase are common in metasomatic vein rocks, as secondary products after ilmenite, titanite, titaniferous magnetite, biotite, etc., and it occurs in nearly every altered titaniferous rock. Kemp[e] states that rutile occurs as a minor constituent, but quite widely distributed, in the copper deposits at Ducktown, Tennessee. He says "it is included in the sulphides precisely as are the bits of garnet, zoisite and amphibole, and is regarded as older than the ores."

A not infrequent occurrence of rutile in the Piedmont region of the Southern Appalachians is as simple and geniculated forms in quartz of quartz veins and stringers. In each instance where this occurrence has been observed the rutile has not been found in quantity, and is only of scientific interest.

An important occurrence of rutile as a primary constituent of rutile-ilmenite-bearing pegmatite dikes[f] has recently been discovered in Goochland and Hanover counties, Virginia, near the eastern border of the Piedmont Plateau, and described on pages 248-261 of this report. Hess[a] has described an interesting association of minerals of the rare-earth metals, including rutile, occurring in the pegmatite at Baringer Hill, Llano County, Texas.

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[a] Watson, Thomas L. and J. Wilbur, A Contribution to the Geology and Mineralogy of Graves Mountain, Georgia, Bull. Phil. Soc., Univ. of Va., Scientific Series, 1912, vol. i, pp. 200-221. References to other localities in the Carolinas cited.

[b] Watson, Thomas L., and Watkins, J. H., Association of Rutile and Cyanite from a New Locality, Amer. Jour. Sci., 1911, vol. 32, pp. 195-200. Taber, S., Geology of the Gold Belt in the James River Basin, Virginia, Va. Geol. Survey, Bull. No. VII, 1912, pp. 27-28, 113-114. These occurrences of rutile are described on pages 262-265 of this report.

[c] Vogt, J. H. L., Problems in the Geology of Ore-Deposits, Genesis of Ore-Deposits, Trans. Amer. Inst. Mng. Engrs., 1901, p. 646. References cited.

[d] Lindgren, W., Metasomatic Processes in Fissure Veins, Genesis of Ore-Deposits, Trans. Amer. Inst. Mng. Engrs., 1901, p. 523.

[e] Kemp, J. F., The Deposits of Copper Ores at Ducktown, Tenn., Trans. Amer. Inst. Mng. Engrs., 1902, vol. xxxi, p. 259.

[f] Hess, F. L., New Rutile Deposits near Richmond, Va., Mng. World, 1910, vol. 33, pp. 305-307.

Rutile occurs as an alteration product of mica in microscopic prisms sometimes parallel to the plane of cleavage; also regularly oriented in certain micas, hematite, and ilmenite; as an alteration product of titanite in eleolite syenite; and as a paramorph after brookite at Magnet Cove, Arkansas.[b] Hintze[c] reports rutile as a pseudomorph after hornblende and feldspar, and after hematite.

MINERAL ASSOCIATIONS.

The mineral associates of rutile include a wide range of species. As a product of crystallization from rock magmas it is associated with most of the common rock-forming silicate minerals, including quartz. When formed in metamorphic rocks by regional metamorphism, the association in addition to the common rock-forming silicate minerals is usually with a group of heavy metamorphic minerals, such as cyanite, magnetite, ilmenite, etc. As a product of veins the commonest associate of rutile is probably quartz, together with other titanium minerals, especially ilmenite, and the oxides of iron. In some veins and pegmatites the association comprises minerals usually regarded as having formed by pneumatolysis, such as the apatite veins of Norway and Sweden, and Canada. In alluvial and water-sorted sands, rutile is associated with the heavy resistant minerals of a variety of mineralogical form, such as ilmenite, magnetite, chromite, monazite, garnet, zircon, spinel, etc., and sometimes gold.

Kunz[d] records the occurrence of rutile in Mexico as circular crystals penetrating opal.

ALTERATION OF RUTILE.

According to Van Hise,[e] rutile alters to hematite, ilmenite, and titanite. He remarks that the alteration of rutile into ilmenite and titanite is not indicated by those who have studied the changes, whether they are deep-seated, but they probably are since they involve liberation of heat and condensation of volume, which normally occur in the zone of anamorphism.[a] Ilmenite alters to rutile and other titanium minerals, which occur in the zone of katamorphism, as the heat and volume reactions correspond, but it is not definitely known whether they occur in the zone of anamorphism.[b]

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[a] Hess, F. L., Minerals of the Rare-Earth Metals at Baringer Hill, Llano County, Texas, Bull. 340, U. S. Geol. Survey, 1908, pp. 287-294.

[b] Iddings, J. P., Op. cit., p. 498.

[c] Hintze, C., Handbuch der Mineralogie, pp. 1592, 1603.

[d] Kunz, G. F., Trans. Amer. Inst. Mng. Engrs., 1902, vol. xxxii, p. 66.

[e] Van Hise, C. R., A Treatise on Metamorphism, U. S. Geol. Survey, Mon. xlvii, 1904, p. 374.

A frequent form of alteration in the Virginia rutile is into a strongly refracting, granular substance, identical, so far as can be observed, with leucoxene, an alteration product of ilmenite. This alteration product, called leucoxene by Gümbel, has been identified as titanite by Cathrein, as anatase by Diller, and as perovskite by Popoff.[c] The alteration in the Virginia rutile progresses along the periphery forming a sharply defined rim, and along fractures in the mineral, which would indicate that the change took place within the katamorphic zone (Pls. IX, fig. 1, and XVI).

Rutile is derived from brookite, ilmenite, octahedrite, and titanite.[d] The change of brookite and octahedrite (anatase) to rutile is a molecular one.[e] Rutile has been observed as a paramorph after brookite at Magnet Cove, Arkansas, and as a pseudomorph after hematite at Binnenthal.[f] Lindgren[g] mentions the alteration of ilmenite to rutile and siderite, and titanite to rutile and calcite, in gold- and silver-bearing veins of deep-seated origin.

GEOGRAPHIC DISTRIBUTION OF RUTILE.

GENERAL STATEMENT.

The known distribution of rutile in quantity to be of commercial value is exceedingly limited. At present, the more important known deposits of this mineral are limited exclusively to two localities in Virginia, and one each in Canada, Europe, and Australia. The localities comprise Virginia in the United States, Bay St. Paul in northern Quebec, Canada, Kragerö in Norway, Europe, and near Mt. Crawford, 25 miles northeast of Adelaide, South Australia. Each of these areas has produced some rutile.

The Virginia rutile deposits form the subject matter of this report, and are of especial interest because of their commercial and scientific importance. They are important commercially because they represent so far as known the only workable deposits of rutile in the United States, and are probably the most extensive deposits yet known in the world; they are of special scientific interest because of their mode of occurrence and particularly their rock associations. There follows below a summary of the rutile occurrences noted in the United States and foreign localities. The occurrences in the United States, excepting those of Virginia, are of scientific interest only, since outside of Virginia none are known to be of commercial value. Of the foreign localities only those deposits known to be of commercial value are described. These include the Bay St. Paul area in Quebec, Canada, the Kragerö area in Norway, and the Mt. Crawford area in South Australia.

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[a] Ibid., p. 231.

[b] Ibid., pp. 227-228.

[c] Iddings, J. P., Rock Minerals, New York, 1906, p. 504.

[d] Ibid., p. 371.

[e] Ibid., pp. 379-388.

[f] Dana, E. S., A System of Mineralogy, 1900, p. 239.

[g] Lindgren, W., The Relation of Ore-Deposits to Physical Conditions. Econ. Geology, 1907, vol. ii, p. 115.

UNITED STATES.[a]

Although the occurrence of rutile is reported from numerous localities in the United States, the mineral has been found in sufficient quantity to be of commercial value in only two states, namely, Pennsylvania and Virginia. At present the known commercially workable deposits are limited to Virginia; those of Pennsylvania were very limited, irregular, and uncertain, as to quantity, and are practically exhausted. With the several exceptions noted above of the large number of localities where rutile has been found, the mineral occurs in such small quantity as to be of scientific interest only. It varies greatly in occurrence in the many localities as to kind of rock and mineral associations. For most of the occurrences very little can be given beyond the mere statement of location of the deposit, since knowledge of them is yet imperfect, owing chiefly to the fact that they have not seemed worthy of time for special study and description.

NEW ENGLAND STATES.

Rutile occurs at many localities in New England, but at none is it found in quantity. With the exception of Rhode Island it is reported from one or more localities in each of the other five states. The occurrences are only of scientific interest. Many handsome specimens of the rutilated quartz found at several localities have been cut for use in jewelry. The known localities where rutile has been found are listed by states below.

Connecticut.

Rutile is reported as occurring at North Guilford; at Lane's mine, Monroe; and in the adjoining town of Huntington. As early as 1836, the rutile of Middletown was cut by Prof. Charles U. Shepard into gems that were almost ruby-red in color.[a]

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[a] Compiled from Dana, E. S., A System of Mineralogy; Hintze, C., Handbuch der Mineralogie; and other sources.

Maine.

At Warren rutile occurs with tremolite and chalcopyrite.

Massachusetts.

Rutile occurs at Barre in gneiss as crystals occasionally an inch and a half in diameter; at Windsor, in feldspar veins penetrating chlorite slate; at Shelburne, in fine crystals in mica slate; at Leyden, with scapolite; and at Conway, with gray epidote.

New Hampshire.

At Lynne, rutile occurs sparingly with tourmaline; and near Hanover as acicular crystals in quartz, which is observed only in loose masses. Magnificent specimens of sagenite ("fleche d'amour"), often cut for use in jewelry, were found in boulders from the vicinity of Hanover from 1830 to 1850, but were not traced to their original source.[b]

Vermont.[c]

Rutile occurrences in Vermont are at Waterbury, Bristol, Dummerston, and Putney; and in middle and northern Vermont in loose boulders as acicular crystals in quartz. Some of the specimens are in transparent quartz and are described as being of great beauty. Hintze[d] records magnificent crystals from Hartford, and rutile needles in rhombohedral dolomite from Middlesex. Kunz[e] describes beautiful sagenite quartz with clove-brown and black rutile needles from Middlesex, and in 1848 from a railroad cut at Waterbury.

MIDDLE NORTHERN STATES.

Rutile occurs in three of the group of middle northern states, namely, New Jersey, New York, and Pennsylvania. In only one of these, Pennsylvania, has it been found in quantity to be of commercial value.

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[a] Kunz, G. F., Gems and Precious Stones, New York, 1890, p. 193.
[b] Kunz, G. F., Op. cit., p. 124.
[c] Amer. Jour. Sci., 1850, vol. 10, pp. 47, 350; Ibid., 1851, vol. 12, p. 389.
[d] Hintze, C., Op. cit., Erster Band, 1907, p. 1620.
[e] Kunz, G. F., Op. cit., 1890, p. 125.

New Jersey.

Rutile is reported found in the granular limestone at Sparta and Newton associated with sapphire and spinel.

New York.

Dana notes the following localities in New York in which rutile is found: In Orange County, one mile east of Edenville, with pargasite in limestone boulders; two miles east of Warwick, in granite with zircon; one mile east of Amity, in quartz with brown tourmaline, and two miles west with spinel and corundum, also two miles southwest with red spinel and chondrodite; near Warwick, in slender prisms penetrating quartz; in New York County, at Kingsbridge, in veins of quartz, feldspar, and mica traversing granular limestone; and in Essex County in limestone.

Pennsylvania.

The occurrence of rutile in Pennsylvania is limited, so far as known, to the central portion of Chester County, in the extreme southeastern part of the State. The earliest published reference to the occurrence of rutile in Chester County, that the writers have been able to find, is in Volume C_4 of the Pennsylvania Survey reports. The statement follows:[a] "In this quarry occur several interesting minerals, the most remarkable being the chesterlite, once regarded as a variety of feldspar; also rutile and feathery talc."

Prior to the year 1901, when the Virginia rutile deposits commenced producing, the demand for rutile in the United States was limited to a few hundred pounds annually, used chiefly in the dental trade, and reported satisfactorily supplied by the Chester County, Pennsylvania, deposits.[b] Only a few pounds of rutile have been produced from the Pennsylvania deposits since 1901. The mineral was picked up from plowed fields during their cultivation and sold for collections and to the dental trade for coloring artificial teeth.[c] The rutile was reported to be well crystallized, in comparatively large crystals, and very pure. Kunz[d] reports double geniculated twins of rutile forming complete circles found near Parkesburg, some of which weighed over a pound each.

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[a] The Geology of Chester County, Vol. C_4, 2d Geol. Survey of Pennsylvania, 1883, p. 71.

[b] Mineral resources of the United States, U. S. Geol. Survey, 1901, p. 278.

[c] Hess, F. L., Mineral Resources of the United States, 1906, p. 530; ibid., 1908, p. 28.

[d] Kunz., G. F., Gems and Precious Stones, New York, 1890, p. 193.

Nothing as yet has been published on the geological occurrence of rutile in Chester County, Pennsylvania, but Prof. F. Bascom,[a] of Bryn Mawr College, who has completed the geological mapping of Chester County, has kindly furnished a statement of the chief occurrence of the mineral.

The formations in which the rutile occurs are highly metamorphosed sediments. Miss Bascom says: "The chief occurrences of rutile in Chester County, and these can hardly be of commercial importance, are (a) in the Cambrian (Chickies) quartz-schist, where it is found weathered out on slopes of the North Valley hills in the neighborhood of Parkesburg, and in railway cuts northeast of Pomerog and west of Atglen. (b) Along the Valley road southwest of Coatesville, where it is weathered out from Cambro-Ordovician (Shenandoah) limestone. Chester Valley and hills are part of an overturned syncline of Paleozoic (Cambrian and Cambro-Ordovician) sediments.[b] (c) Rutile also occurs in Cambro-Ordovician limestone in the Doe Run region south of Coatesville and of Chester Valley. This limestone lies on a folded thrust-plane with pre-Cambrian gneiss above and below it. (d) At the County Poor-house quarry (West Bradford) south of Chester Valley, in similar limestone, also in East Bradford."

SOUTHEAST ATLANTIC STATES.

Of the southeast Atlantic states rutile is found in Alabama, Georgia, North Carolina, South Carolina, and Virginia. Prior to 1900, when the Nelson County area in Virginia was opened, it was not known that rutile occurred at any place within the southeastern territory in sufficient quantity to be of commercial value. It was found of gem grade at many localities within this region, and it was cut and used in jewelry. Until the opening of the Virginia deposit in 1900, the most noted rutile locality in the South was that of Graves Mountain, Lincoln County, Georgia, which has supplied the collections of the world, and to some extent has supplied rutile for gem purposes.

Alabama.

Very little is known of the occurrence of rutile in Alabama. The State Geological Survey reports contain very few references to the mineral. In the report for 1874 mention is made of the occurrence of rutile in Section 3-T. 20-R. 16, Chilton County, in mica schist in close proximity to a pegmatite dike. Similar occurrences in pegmatite dikes cutting mica schist have been noted in Coosa and Randolph counties.[a]

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[a] Personal communication from Dr. Florence Bascom, Feb. 7, 1910.

[b] See Philadelphia folio (No. 162) on region to the east. Geologic Atlas of the United States, U. S. Geol. Survey, 1909.

Georgia.

The known occurrences of rutile in Georgia are limited to Habersham and Lincoln counties, but that of Graves Mountain, Lincoln County, is the only one of importance.

Graves Mountain.[b]

Location and topography.—Graves Mountain lies in the extreme western part of Lincoln County, Georgia, within less than a mile of the Wilkes County boundary; 10 miles nearly east of Washington, the county seat of Wilkes County; 6 miles southwest of Lincolnton; and about 40 miles northwest of Augusta (map, fig. 1). It is within but near the eastern border of the Piedmont Plateau province, a short distance north of the "fall-line."

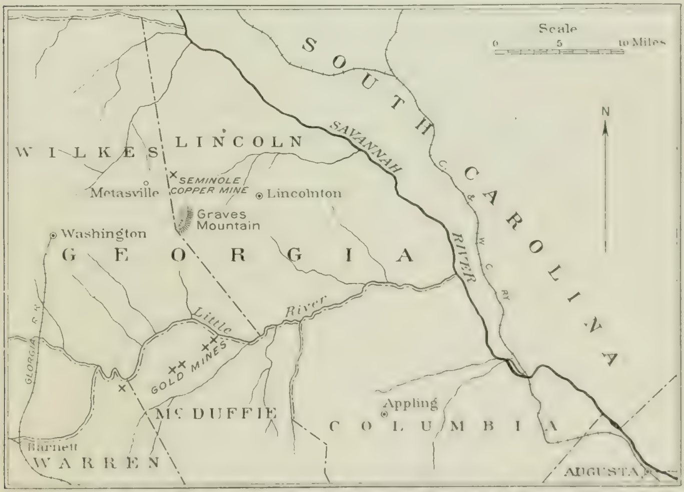

Fig. 1.—Map of middle northeast Georgia showing location of Graves Mountain in Lincoln County.

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[a] Personal communication from Dr. Eugene A. Smith, State Geologist of Alabama, April 3, 1911.

[b] Abstracted from "A Contribution to the Geology and Mineralogy of Graves Mountain, Georgia," by Watson, Thomas L. and J. Wilbur, Bull. Phil. Soc., Univ. of Va., Scientific Section, 1912, vol. i, No. 7, pp. 201-221.

Graves Mountain is a conspicuous ridge (monadnock) of unreduced hard rock, which rises to an altitude of 700 feet above tide-level, and several hundred feet above the Piedmont Tertiary base-leveled plain. It has a length of 2 miles along an approximate northeast-southwest direction, coincident with the general structure of the rocks of the area, and is less than half a mile in average width. The slopes of the mountain are very unequal, being less steep on the northwest side, which is the direction of dip, than on the southeast side. The upper portion of the ridge is greatly scarred and roughened from weathering, and low and high cliffs are numerous.

Geology.—The rock composing Graves Mountain is a fine-grained quartzite. It varies from moderately thinly foliated to essentially massive in structure. Its position is along the northwest margin of a metamorphic sedimentary series of crystalline rocks. The dip of the quartzite is toward the northwest at a variable angle and the strike is north-northeast. No igneous rocks have been observed at Graves Mountain, but they are known at other localities within the general area. The basal portion of the mountain and for some distance up the slope on the northwest side the rock is the foliated variety quartzite-schist, while the crest and for an undetermined distance down the slopes the rock is massive quartzite, with only a slight tendency to schistosity indicated. On top of the mountain the quartzite is cut by quartz veins, some of the larger ones of which measure several feet in thickness. These are apparently barren, but smaller quartz veins only a few inches wide contain rutile and iron oxide. The rock from some of the small openings shows fracturing and brecciation.

The quartz schist is composed of quartz and less sericite as the essential minerals, with cyanite and occasional small grains of rutile and black oxide of iron as the principal accessory minerals. A partial chemical analysis of this rock made by J. Wilbur Watson gave: SiO_2, 79.18 per cent; Al_2O_3, 14.14 per cent; and Fe_2O_3, 3.17 per cent. The rutile occurs microscopically as euhedral and anhedral crystals formed along the boundaries of the quartz grains and as inclusions in the quartz and cyanite.

The massive quartzite which occurs on the crest and higher slopes of the mountain, has essentially the same composition as the quartzite schist. It is fine-grained in texture, composed largely of fine, sugary quartz, some muscovite, and in places contains abundant large and small tables of cyanite of pale green color when fresh, crystals of blue lazulite, and small grains of red rutile. Pyrophyllite is rather common. Cyanite, lazulite, and rutile are usually intimately associated, the first two (cyanite and lazulite) are frequently imbedded one in the other, and the rutile occurs as separate grains and as inclusions in the other minerals. A partial chemical analysis of the rock collected on top of the mountain gave J. Wilbur Watson the following result: SiO_2, 69.74 per cent; Al_2O_3, 24.86 per cent; and Fe_2O_3, 0.53 per cent.

Graves Mountain has long been known for the occurrence of an interesting association of rather uncommon minerals, including rutile, pyrophyllite, lazulite, cyanite, and hematite. Knowledge of the occurrence of the interesting group of minerals at this locality was first made known by Prof. C. U. Shepard in a paper published in 1859.

Rutile.—Knowledge of the occurrence of rutile at Graves Mountain was early made known by Prof. C. U. Shepard,[a] who was the first to describe and work it. According to Kunz,[b] the rutile from this locality has realized at least $20,000 for cabinet specimens and has supplied the collections of the world. The rutile was won from the central depression on top of the ridge and along the northwest slope. The openings are of long standing and had so greatly caved at the time of the senior writer's visit in March, 1911, that they were largely obscured.

No specimens of coarse rutile were observed by the senior writer during his visit but it is plentiful in every specimen collected, chiefly as microscopic inclusions in other minerals and frequently as small crystals and grains visible to the naked eye. It has been observed megascopically in the quartzite, and in intimate association with cyanite, lazulite, pyrophyllite, and hematite. As a microscopic accessory rutile in crystals and formless grains of red and reddish-brown color has been identified as inclusions in the lazulite, cyanite, pyrophyllite, hematite, and quartz, and formed along the boundaries of these minerals. In each case it shows the usual optical properties.

Veatch[c] observed rutile with quartz and iron oxide in veins not exceeding a few inches in width on top of the mountain. The rock fragments thrown out of the small pits in this position show fracturing and brecciation, and formation of the vein rutile was probably subsequent to the fracturing of the quartzite, but a part of it may have existed in the veins prior to the crushing.

The coarse rutile crystals from this locality observed in the various mineral collections in this country are lustrous black to reddish-brown and red, with brilliant orange-red in thin sections. They vary in size usually up to 5 inches and occur both as single and twin forms. Kunz[a] reports fine single crystals have been found up to four pounds each and with it interesting hydrous anthophyllite. The single crystals are usually of prismatic habit and frequently show pyramidal terminations.

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[a] Shepard, C. U., Amer. Jour. Sci., 1859, vol. 27, p. 36; Ibid., vol. 28, p. 141.
[b] Kunz, G. F., N. C. Geol. Survey, Bull. No. 12, 1907, p. 52.
[c] Personal communication, January, 1912.

Besides the common forms of rutile crystals this locality has furnished some rather rare and interesting ones, which have been figured and described chiefly by German crystallographers,[b] especially Rose, Haidinger, vom Rath, and Mügge. Especially interesting are the beautiful rutile twins figured and described by Rose and others, composed of as many as sixfold and eightfold twins commonly known as sixlings and eightlings; those made up of a less number of parts such as trillings and fourlings being not uncommon from the Georgia locality.

The three following analyses quoted by Hintze[c] serve to show the essential chemical composition of the Graves Mountain rutile.

Analyses of rutile from Graves Mountain, Georgia.

	Per cent.	*Per cent.*	*Per cent.*
TiO_2	97.22	97.52	97.64
Fe_2O_3	2.62	2.64	2.61
Total	99.84	100.16	100.25

While coarse rutile was not observed at this locality by the senior writer, careful examination of the dumps alongside the numerous openings on the northwest slope of the mountain, from which the mineral was mined, and the presence of rutile in microscopic proportions in thin rock slices, clearly indicate the rutile matrix to be a heavy, dark-colored rock, composed of an aggregate of long-bladed and coarsely columnar crystals of cyanite and massive granular hematite, with usually some quartz. Frequently the rock is composed of excessive hematite with less cyanite, and as often cyanite may predominate. In either case the rock presents a more or less porous texture which is perhaps most pronounced in specimens showing dominant cyanite. Professor Shepard's description of the occurrence of rutile in this rock follows. He says:[d]

> "The central part of the mountain, to the thickness of 50 feet, is composed of a hematitic rock, which includes in some places an abundance of a ferruginous kyanite,

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[a] Personal communication, Feb. 28, 1910.

[b] See Dana, E. S., A System of Mineralogy; and Hintze, C., Handbuch der Mineralogie, for references.

[c] Hintze, C., Handbuch der Mineralogie.

[d] Shepard, C. U., Op. cit., 1859.

> much resembling in appearance the diaspore from the Urals. With the kyanite is found rutile, often in gigantic crystals (weighing upwards of a pound), and possessed of much regularity of crystalline form. The prevailing figure is a square prism with truncated lateral edges, and surmounted at both extremities by an eight-sided pyramid. There is also found a most remarkably perfect twin crystal, in which the geniculation is six times repeated,—producing an hexagonal prism, surmounted at each end by a six-sided pyramid, with a reëntering, six-sided hopper-shaped cavity, at the tips. These crystals are all more remarkable for their symmetry and polish, than any I have ever seen. Some are fully equal in lustre to the brilliant crystals of cassiterite from Cornwall or Bohemia. The most perfect rutiles are generally imbedded in the massive kyanite; and when detached leave behind impressions having a polish and lustre equal to that of their own planes. A little common quartz is also mingled with the kyanite and rutile.
>
> "Closely associated with kyanite, rutile and quartz are considerable masses (8 or 10 inches thick) of a mineral known among the miners of Georgia as steatite, but which is true pyrophyllite,—differing in no respect from that of the Urals, except in the finer stellulations it presents and in the slight ferruginous stain it exhibits near their centres."

The production of rutile from the Georgia locality has been for cabinet specimens chiefly, and to some extent for the gem trade.

The Carolinas.

During recent years a small production of rutile has been reported from the Carolinas from time to time in washing for monazite. The production has been chiefly from near Ellenboro, Rutherford County, North Carolina, and near Gaffney, Cherokee County, South Carolina. In 1906, the production of rutile from this source was too small to be reported and there has been none since. The workable deposits of monazite, containing some rutile in places, are confined chiefly to the gravels and sands of stream beds, derived by weathering from the granites, gneisses, and schists. The Carolina gneiss, mapped by the U. S. Geological Survey as Archean in age, is the most important formation from which the placers are derived.[a]

North Carolina.—Rutile in various mineralogical associations has been reported from more than 20 counties in North Carolina, but so far as known it does not occur in quantity. Many localities have furnished rutile of gem grade, and the State has yielded more rutilated quartz of unexcelled beauty for gem purposes than all of the American localities combined.[b] Specimens of rutilated quartz have come from many places in Randolph, Catawba, Burke, Iredell, Jackson, and Alexander counties; also from the monazite mines in association with handsome garnets, near Shelby, Cleveland County.

Hess[c] reports a sample composed of ilmenite, magnetite, and rutile taken from a large deposit of titaniferous iron occurring north of Lenoir, North Carolina. The deposit, according to the same authority, is reported to contain 37 to 41 per cent TiO_2; and one firm that used the ore reported that it was readily converted to ferrotitanium, containing 35 to 40 per cent titanium, and which, by a second process, could be made to contain 65 per cent titanium.

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[a] Sterrett, D. B., Mineral Resources of the U. S., 1906, p. 1197.

[b] Kunz, G. F., N. C. Geol. and Economic Survey, Bull. No. 12, 1907, p. 33

[c] Hess, F. L., Mineral Resources of the U. S., 1906, p. 530.

The localities[a] in North Carolina from which rutile has been reported are: At Crowder and Clubb mountains, Gaston County, in association with pyrophyllite and cyanite; at the Culsagee mine with corundum, Macon County; at Hogback mine, Jackson County; at Beattie's Ford, Mecklenburg County; at Buckhorn Falls, Chatham County; at Cane Creek, Mitchell County; at many places in Iredell and Alexander counties; at Bryson, Swain County; at Honey Creek, Wilkes County; in the gold sands of Burke, McDowell, Rutherford, and Polk counties; at Pilot Mountain, Randolph County; and in Clay, Yancey, Catawba, Cabarrus, and Lincoln counties.

Pratt[b] reports large black rutile crystals, single and twinned, found quite abundantly loose in the soil near Elf Post-office, Clay County; very brilliant crystals of rutile, both single and twinned, in beautifully radiated pyrophyllite, near Efland, Orange County; and simple prismatic crystals one-fourth inch long and well terminated, on Buckner Branch, Swain County.

South Carolina.—The principal occurrence of rutile in South Carolina is as loose grains and crystals in the monazite sands, especially near Gaffney, Cherokee County. Rutilated quartz (fleche d'amour) is also reported from the monazite belt and rutile crystals are found in the vicinity of Prosperity, Newberry County.[c] Rutile crystals of outward dark gray color but reddish-brown on fracture surface and which show some wear are found in Kershaw County.[d]

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[a] Genth, F. A., and Kerr, W. C., The Minerals and Mineral Localities of North Carolina, Raleigh, 1885, pp. 35-36.

Dana, E. S., A System of Mineralogy, 1900, p. 239.

Hintze, C., Handbuch der Mineralogie, 1907, pp. 1618-1619.

[b] Personal communication from Dr. Joseph Hyde Pratt, State Geologist of North Carolina, Jan. 25, 1911.

[c] Sloan, Earle, Catalogue of the Mineral Localities of South Carolina, S. C. Geol. Survey, 1908, p. 157.

[d] Collection of rutile crystals donated by Dr. J. W. Mallet of the University of Virginia.

STATES WEST OF THE MISSISSIPPI RIVER.

The states west of the Mississippi River in which rutile occurrences have been recorded include Arkansas, California, Colorado, South Dakota, and Texas. Of these, Magnet Cove, Arkansas, is the most noted locality.

Arkansas.[a]

Hessenberg, in 1864, was the first to make mention of the occurrence of rutile at Magnet Cove. Much has been published since on the mineralogy of this locality. According to Williams, rutile occurs at Magnet Cove, commonly associated with brookite and perovskite, and as paramorphs after brookite. The rutile crystals very seldom occur as single individuals, but are found as twins according to some one of the various twinning laws. Some of the most interesting forms are the sixlings and eightlings, figured and described by G. vom Rath. At the southwest corner of the Cove, in Perofskite Hill, rutile crystals were formerly reported to be exceedingly plentiful, and are said to be quite common still. At the brookite locality, at the southeast corner of the Cove, rutile was reported by Williams to be not at all uncommon. He described the rutile as a contact mineral formed on the sandstones associated with the novaculites, and regards the syenite as the source of the titanium. Although the Magnet Cove area has long been one of scientific interest and much has been published on the mineralogy of it, the rutile has not proved to be of commercial importance.

California.

The only locality in California from which rutile has been reported is in Nevada County where Lindgren[b] has described it as occurring.

Colorado.

In Colorado rutile is reported from St. Peter Dome[c] and West Cheyenne Canon in El Paso County. That from the former locality (St. Peter's Dome) is black and belongs to the ferriferous variety nigrine. An analysis of the rutile shows:

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[a] Hintze, C., Handbuch der Mineralogie, Erster Band, 1907, pp. 1615-1617. References cited.

William, J. F., The Igneous Rocks of Arkansas, Geol. Survey of Arkansas, 1891, vol. ii, pp. 303-330. References cited.

[b] Lindgren, W., Ztschr. f. prakt. Geol., 1902, 20. Quoted by Hintze, C., Op. cit., p. 1615.

[c] Smith, W. B., Proc. Col. Sci., 1887, vol. 2, p. 175.

Groth's Ztschr., vol. 17, p. 417.

Analysis of rutile from St. Peter's Dome, Colorado.

	Per cent.
TiO_2	94.93
Fe_2O_3	3.77
SiO_2	1.37
H_2O	0.71
	100.78
Specific gravity	4.288

The flesh-colored orthoclase from West Cheyenne Canon, El Paso County, contains minute black crystals of rutile, not in contact with the feldspar but generally implanted in the more recent quartz.[a]

Genth and Penfield give the following analysis of the rutile:

Analysis of rutile from West Cheyenne Canon, Colorado.

	Per cent.
TiO_2	91.96
Fe_2O_3	6.68
SnO_2	1.40
	100.04

South Dakota.[b]

Black rutile with brilliant metallic lustre occurs in the granite of the Black Hills, South Dakota, and Headden has described crystals of the mineral from the Harney Peak district. He states that the crystals are found in aggregates usually surrounded by and always associated with muscovite in a mass of feldspar. Two analyses of the rutile yielded:

Analyses of rutile from the Black Hills, South Dakota.

	Per cent.	Per cent.
TiO_2	90.78	90.80
FeO	8.10	7.92
SnO_2	1.32	1.38
MnO	trace	trace
	100.20	100.10

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[a] Genth and Penfield, Contributions to Mineralogy, Amer. Jour. Sci., 1892, vol. 44, pp. 384-5.

[b] Headden, W. P., On Black Rutile from the Black Hills, Amer. Jour. Sci., 1891, vol. 40, pp. 249-250.

Hintze, C., Handbuch der Mineralogie, 1907, p. 1620.

Dana, E. S., A System of Mineralogy, 1900, pp. 238, 239.

Texas.

Hidden[a] reports the occurrence of the sagenitic variety of yellow rutile upon smoky quartz crystals, at Baringer Hill, Llano County, Texas. Hess[b] reports rutile from the same locality in prismatic and reticulated forms one-fourth inch thick.

CANADA.[c]

The occurrence of rutile has been noted at a number of localities in the provinces of Quebec, Nova Scotia, Ontario, and the Yukon Territory, but, with the exception of the St. Urbain locality in the Province of Quebec. none of the occurrences so far observed in Canada has proved to be of commercial value.

QUEBEC.

St. Urbain Deposits.[d]

The principal occurrence of rutile known in Canada is located 2 miles west of the little village of St. Urbain in the parish of the same name, which is located about 10 miles north of Bay St. Paul, on the River Gouffre, in Charlevoix County, Province of Quebec.

The ilmenite and rutile of the St. Urbain deposits, like many other occurrences of ilmenite, are contained in anorthosite, which apparently has large but unknown areal extent. The anorthosite is poor in femic minerals and locally the rock shows some crushing. The feldspars which are chiefly andesine show evidence of strain. The larger ilmenite bodies have in general the form of elongated masses some of which show dikelike outlines. The direction of elongation of the bodies conforms to an indistinct gneissoid structure (east-west direction) in the anorthosite; the contacts between the ilmenite bodies and the anorthosite are usually sharp though some gradation occurs in places. There is frequently developed along the contacts a narrow band of dark brown mica.

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[a] Hidden, W. E., Some Results of Late Mineral Research in Llano County, Texas. Amer. Jour. Sci., 1905, vol. 19, pp. 425-433.

[b] Hess, F. L., Minerals of the Rare-Earth Metals at Baringer Hill, Llano County, Texas, Bull. No. 340, U. S. Geol. Survey, 1908, p. 292.

[c] Personal communication from Dr. R. W. Brock, Director, Geol. Survey of Canada, Oct. 22, 1910. List of occurrences of rutile in Canada prepared by Mr. R. A. A. Johnston, Mineralogist of the Canadian Geological Survey.

[d] The description of the St. Urbain deposits in the Province of Quebec is abstracted from the recent comprehensive published paper by Dr. Charles H. Warren, entitled "The Ilmenite Rocks Near St. Urbain, Quebec; A New Occurrence of Rutile and Sapphirine," Amer. Jour. Sci., 1912, vol. xxxiii, pp. 263-277. See also brief statement by Mr. Theo. Denis in the Canadian Mining Journal, 1911, Jan. 1, p. 11.

Most of the ilmenite bodies appear to be free from rutile. One of the most important exposures of the ilmenite rock found directly west of the village of St. Urbain, consists megascopically essentially of a dense black, medium- to rather coarse-grained ilmenite, with scattered small grains of feldspar or its decomposition products, occasional grains of dark green spinel (pleonaste), and plates of dark brown mica. All the minerals lack crystallographic boundaries, and the ilmenite grains range in size from 3-4 mm. to 10-12 mm. in cross section, with an average perhaps of 6-7 mm. The general average amount of accessory minerals in the ilmenite body is from 5 to 6 per cent, but considerable portions of it will not contain more than 2.5 per cent. In discussing the composition of the ilmenite Dr. Warren developed many facts which strongly point to the conclusion that hematite is in intimate crystallographic intergrowth with ilmenite, and the ilmenite and hematite molecules are not isomorphous as so commonly reported for other localities.

A few thousand tons of ilmenite are reported to have been mined for iron by an English company from this ore-body during the late seventies. Dr. Warren states that the ruins of an old furnace may still be seen just below the deposit.

The rock that is of chief interest is a rutile-sapphirine-bearing ilmenite, which occurs with rutile-free ilmenite, the two forming a large mass inclosed in anorthosite. The rutile-bearing rock is brownish-black in color, and consists of rather finely granular ilmenite sprinkled with grains of orange-red rutile, feldspar (andesine) like that of the anorthosite, biotite, sapphirine, or their decomposition products, and spinel. With the exception of spinel inclusions in some of the feldspar grains the mineral constitutents are without crystal boundaries. Microscopically ilmenite forms a background in which the other minerals lie.

The rutile is described as developed in simple crystal grains or clusters, with slight pleochroism, exhibiting good cleavage, but rarely twinned. In size the rutile ranges from mere specks up to grains having a diameter of 3.5 mm., the average being about 0.6 mm. It is reported to be quite uniformly distributed through the ilmenite and is also associated with the other minerals, being sometimes inclosed by them. An occasional grain of apatite has been noted. There is no magnetite present, and the rutile in different samples varies considerably, estimated from 8 to 20 per cent on polished specimens.

A chemical analysis made on a sample of the rutile-rich type yielded the following result:

Analysis of rutile-sapphirine-bearing ilmenite from St. Urbain, Quebec.
(R. S. ANDERSON, *Analyst.*)

	Per cent.
SiO_2	2.24
TiO_2	53.35
Al_2O_3	1.65
Fe_2O_3	13.61
FeO	24.49
MnO	0.30
MgO	4.04
CaO	0.30
	99.98

Dr. Warren regards the rutile-bearing rock as a magmatic differentiation product in which there was an excess of titanic oxide and a smaller excess of magnesia and alumina. It represents an extreme and new ultra-basic type of igneous rock, and Dr. Warren has proposed the name *urbainite* for it. No attempt has been made to classify it in the quantitative system but it falls into a new position in the perfemane class (V), possibly close to the rutile nelsonites of Nelson County, Virginia, described later in this volume.

The St. Urbain deposits were leased and worked by the General Electric Company, and a considerable quantity of the ore was reported mined by the company in 1910 from an open cut, and shipped to Schenectady, New York. It is reported that the property has not been operated for several years.

Other Localities.

Until the St. Urbain deposits were exploited and worked in 1910, the best known locality for rutile in Canada was in the township of Templeton, Ottawa County. Here rutile occurs in crystals some of which are quite large, occasionally as geniculated twins, associated with actinolite, barite, and dolomite. A few years ago considerable prospecting work was carried on with a view to developing the property, but the results were disappointing, as the deposit was to all appearances soon exhausted. Recently a bowlder consisting of a similar association as that indicated above was found in the adjoining township of Buckingham, the origin of which has not been traced.

Rutile has been noted elsewhere in the Province of Quebec in small crystals in chlorite schist in the township of Sutton, Brome County, and in the auriferous gravels of Riviere du Loup, Beauce County. These occurrences are of minor character and are not at all likely to become of commercial importance.

Mr. Denis reports extensive deposits of titaniferous iron ores of similar nature to the St. Urbain ilmenite ores as occurring at Seven Islands Bay on the north shore of the Gulf of St. Lawrence; in the Lake St. John district in the vicinity of Lake Kenogami and at Ile d'Alma at the discharge of Lake St. John; and in the vicinity of St. Jerome in Terrebonne County. There are no data available as to the commercial possibilities of these occurrences, since the presence of rutile in them is unknown.

NOVA SCOTIA.

In the Province of Nova Scotia rutile has been observed in minor quantity at Scots Bay, Kings County, and at Mooseland, Halifax County.

ONTARIO.

Small occurrences of rutile have been observed at a number of localities in Ontario. In the township of Madoc, Hastings County, it is found in crystals in limestone on Green Island, Moira Lake; in the adjoining township of Marmora it occurs in veins with chlorite; at the Wallace mine, Bay of Islands, north shore of Lake Huron it occurs in delicate acicular crystals lining quartz cavities; and in the district about Lake Temogami it forms slender crystals penetrating biotite.

YUKON TERRITORY.

In Yukon Territory a compact, massive form of rutile has been observed in small quartz veins on Thistle Creek, one of the smaller tributaries of Yukon River.

AUSTRALIA.

Rutile occurs at a number of localities in Queensland and South Australia. Very little is known of the occurrences in Queensland. In South Australia, about 25 miles northeast of Adelaide in the vicinity of Mount Crawford (3 miles southwest) and Blumberg (7 miles west of north), desultory mining of rutile has been engaged in with reported small shipments of the ore.

QUEENSLAND.

Recently rutile has been reported as occurring at several localities in Queensland, but the writers have been unable to obtain any information relating to the geology of the individual districts. In the Walsh and Tinaroo mining districts ore containing from 50 to 90 per cent rutile was reported; the heavier specimens contained an excess of iron and were of no commercial value.[a] It is also reported that the back country at Cairns can supply rutile in quantity,[b] and that six loads of the ore were obtained from another locality 4 miles south of White Springs.[c]

SOUTH AUSTRALIA.

The known occurrences of rutile in South Australia are near Mount Crawford, section 119, hundred of Para Wirra; and sections 6 and 9, hundred of Talunga, six miles north of Blumberg, about 25 miles northeast of Adelaide, and 16 miles from Gawler railway station. Practically nothing has been published on the geology of these occurrences. They are briefly described below.

The occurrence of rutile in sections 8 and 9, hundred of Talunga, 6 miles north of Blumberg, has been described by Mr. Gee as follows:[d]

> "From time to time, for many years past, work has been carried on by various parties, but apparently in no instance has there been much enterprise or energy. The workings, which continue for about 150 yards in length, are principally a number of small shafts, cross trenches, and surface openings, from 3 feet to 30 feet in depth, disclosing a soft clay kaolinized dike formation, from 10 feet to 12 feet wide, striking slightly east of south. Through this material rutile crystals in various forms, both coarse and fine, can be seen, in some places dispersed throughout the matrix, in others in pockets and seams, and can be extracted by dish washing. For some distance on each side of the formation fine rutile can be obtained on the surface, but the most valuable is in a small seam of gravel resting on a clay bed about 12 inches below the surface, and which yielded very good prospects indeed, much better than had been anticipated, judging from the débris on the surface, and its position not being on the line. The better class material is at each end of the workings. From each of those several samples were taken, also from the surface and shallow pits, which, when bulked, gave an average return of 1¼ per cent."

Hand specimens of the ore,[e] obtained from the leases of Mr. Francis J. Spence, show chiefly a granular mixture of dark red rutile and light-colored silicate minerals, the principal ones of which are sericite, sillimanite, occasional feldspar, and quartz. Pressure effects are plainly visible in fractures in the rutile and quartz, and in the orientation of the sericitic shreds and fibres of sillimanite, both of which are much curved and bent. The larger specimen is composed chiefly of granular rutile encased in or wrapped about by thin laminæ of sericite and a little quartz. A sawed surface of the specimen shows numerous irregular fractures in the rutile, some of which are filled by stringers of sericite frequently penetrating inward from the outer laminæ of the same mineral. There is strong indication in places, especially about the margin of the specimen, of interleaving of the rutile with the mica.

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[a] Australia Mining Standard, Dec. 11, 1907.

[b] Ibid., Dec. 11 and 25, 1907.

[c] Ibid., Dec. 25, 1907, p. 580.

[d] Record of the Mines of South Australia, 4th ed., pp. 356-357.

[e] Specimens donated by Mr. Frank L. Hess of the U. S. Geol. Survey, Washington, D. C.

A thin section cut from the specimen and examined under the microscope showed massive anhedral grains of deep red rutile slightly pleochroic, but possessing good cleavage and in most cases twinning. Inclusions of a black opaque metallic mineral occur in the rutile which probably are ilmenite. Pressure metamorphism is evidenced in the frequent lines of fracture crossing the rutile grains along which some alteration to leucoxene has progressed. There occur small grains of quartz and occasionally shreds and folia of colorless mica partly admixed with or disseminated through the rutile, and partly filling fractures, indicating in the latter occurrence probable secondary origin.

In another specimen of the ore rutile is associated with much sillimanite in grouped felt-like aggregates with silky lustre, and quartz. Sericite can be observed very sparingly. The specimen indicates considerable mashing from pressure metamorphism.

Microscopic study of a thin section cut from this specimen showed the mineral composition to be chiefly rutile, with sillimanite, quartz, and feldspar (mostly plagioclase), together with a few microscopic accessory minerals as inclusions in the quartz and feldspar. The rutile, red to red-brown in color, and in some cases showing cleavage and twinning and at times appreciable pleochroism, occurs chiefly in massive granular form and in aggregates of granules and microscopic crystals having good outward crystal form. It is quite free from inclusions but contains inclosures of the silicate minerals, especially quartz. Much sillimanite is present, occurring in aggregates of fibres with partial radiating arrangement penetrating the quartz and feldspar. Some of the fibres terminate abruptly and some are very finely pointed. In some cases the sillimanite fibres are broken across at right angles to their longer direction. Broken fibres of sillimanite, fractured rutile and quartz, and slight optical disturbance and partial granulation of the quartz, are pressure effects shown in the thin section. Plate III, fig. 1, a microphotograph of the thin section, serves to illustrate the principal features mentioned above.

There are in the mineralogical collections of the University of Virginia several specimens of rutile labeled Blumberg, South Australia, which show similar associations and general characters to the specimens described above. These specimens likewise bear marked evidence of mashing from pressure

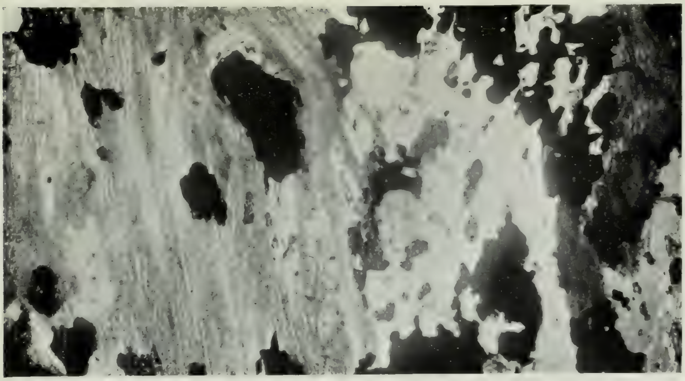

Fig. 1.—Rutile-bearing pegmatite (?) from South Australia. Black areas rutile, light areas in right half of figure feldspar and quartz, medium-gray and light fibrous areas in left half sillimanite. Nicols crossed. Enlarged 30 diameters.

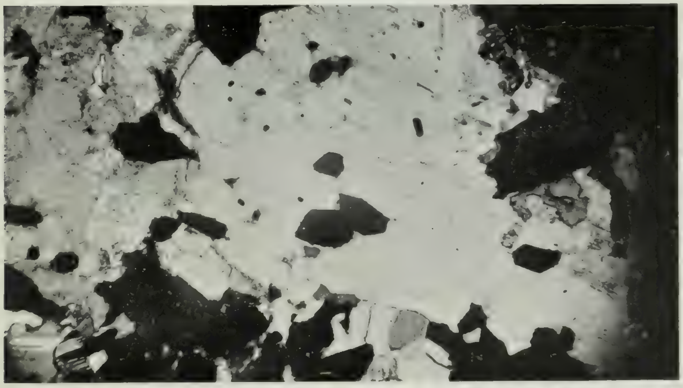

Fig. 2.—Kragerite, a rutile-bearing aplite, from Kragerö, Norway. Black grains and crystals are rutile, light areas chiefly sodic feldspar (albite-oligoclase). Nicols crossed. Enlarged 30 diameters.

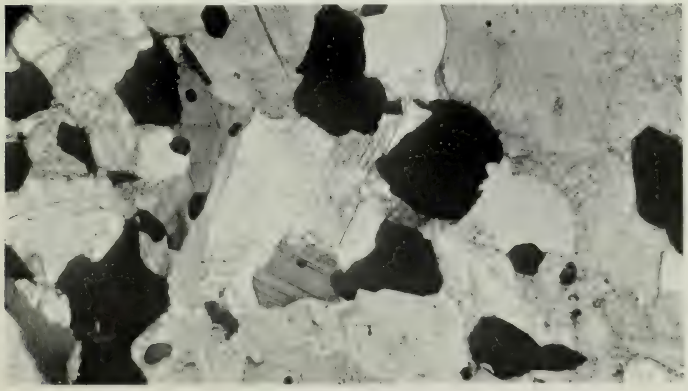

Fig. 3.—Kragerite, from Kragerö, Norway. Same as fig. 1. Nicols crossed. Enlarged 30 diameters.

PHOTOMICROGRAPHS OF RUTILE-BEARING ROCKS FROM NORWAY AND SOUTH AUSTRALIA.

metamorphism. One of the specimens is composed chiefly of kaolinized feldspar with greenish scales of sericite, and large and small grains of red rutile, more or less segregated as very minute stringers which lie for the most part in the foliation of the rock.

The mode of occurrence of the South Australia rutile is unknown, but from the brief statement of Gee it seems not improbable that the rutile is found in pegmatite. Except for the presence of sillimanite in several specimens, the hand specimens of the ore examined afford no positive evidence against pegmatitic occurrence. The sillimanite-bearing specimens might readily have come from contact positions.

NORWAY.

The occurrence of rutile has been noted at a number of localities in Norway, but the one of most importance commercially is in the neighborhood of Kragerö on the southeast coast.

According to Vogt rutile occurs in the apatite veins of Norway and north Sweden in sufficient quantity oftentimes to be mined. The veins are connected with gabbro, and were formed soon after the eruption of the rock, which shows characteristic pneumatolytic metamorphism. Chlorine, with very little fluorine, is present in the veins in the form of the minerals scapolite and chlorapatite. Besides rutile there occur other titanium minerals, especially ilmenite and titanite, and the veins often contain some pyrite, and exceptionally a little tourmaline.[a]

KRAGERÖ.

Introduction.—According to Professor Brögger[b] the occurrence of rutile in the neighborhood of Kragerö is confined to a large aplitic dike situated 200 to 300 meters from the sea and about 100 meters above sea-level, and is referred to as a rutile-aplite. The rock is an even-granular white aplite practically without trace of dark silicate minerals. Brögger refers to the occurrence of rutile in the middle part of the dike as being uniformly distributed through the rock in grains 0.5 to 2 mm. in size, and estimated roughly to amount to about 5 to 10 per cent by weight.

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[a] Vogt, J. H. L., Problems in the Geology of Ore-Deposits, Trans. Amer. Inst. Mng. Engrs, 1901, pp. 646-647; also see references to work by Prof. Vogt in Zeitsch. f. prakt. Geologie, 1894-1897.

Brögger, W. C., and Reusch, H. H., Vorkommen des Apatite in Norwegen. Deutsche Geologische Gesellschaft-Zeitschrift, 1875, Band xxvii, pp. 646-702.

[b] The statements which follow below have been taken partly from a report made by Prof. W. C. Brögger, Oct. 5, 1904; and from the following paper by Watson, Thomas L., Kragerite, A Rutile-Bearing Rock from Krageroe, Norway, Amer. Jour. Sci., 1912, vol. xxxiv, pp. 509-514.

A second, and commercially the most important, occurrence of rutile in the aplite is referred to as stripes or schlieren of local enrichments of the mineral. Most of the schlieren consist almost exclusively of rutile, and these portions of the rock crumble easily to a grainy rutile powder. The rutile schlieren are unequally distributed through the dike, with the richest ones essentially concentrated in a few zones, the largest of which is situated about in the middle of the dike.

In 1904, Professor Brögger discussed the rock as a new member of the aplite series and named it *kragerite*. Concerning this Prof. J. H. L. Vogt[a] says:

> "Brögger discussed a new rock, kragerite, a new member of the aplite series. The rock is of practical interest on account of its content of rutile. In theoretic connection, the speaker considered this rock, which consists almost exclusively of albite and rutile, as a differentiation product of a gabbro magma, analogous to the appearance of lestiwarite, an aplitic differentiation product of a nepheline syenite magma, etc. In addition mention was made, by analogy, of routivarite, anorthosite, and oligoclasite. The content of titanic acid in the kragerite was attributed to pneumatolytic processes during formation."

Professor Vogt states, in a personal communication to the senior writer, that the rock has been found only at a single place in the neighborhood of Kragerö, and has not great areal extent. It has been worked in later years for rutile, the percentage of which is very variable.

General description.—The rutile-bearing rock[b] (kragerite) from Kragerö, Norway, submitted to analysis is medium-grained, of light color, and granitic texture. Its most prominent megascopic constituents are light gray and pinkish feldspars and much black rutile, with a little quartz. Several small areas of a green ferromagnesian mineral, probably pyroxene partly altered and associated with rutile, were noted. The feldspar and quartz grains measure 1 to 2 mm. in size; the rutile grains rarely exceed 1 mm. and much of it is less than 0.5 mm. The quantity of black rutile and the reddish color of a part of the feldspar increase the depth of color of the rock. Most of the feldspar shows fine albitic twinning on cleavage surfaces under a pocket lens. The rutile, which is black and highly lustrous, is partly disseminated as small grains through the rock, but most of it appears to be segregated along roughly parallel lines, suggesting the appearance of imperfect foliation, which Professor Brögger refers to schlieren of local enrichments of the mineral.

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[a] Proceedings of the Scientific Society of Christiania, Dec. 2, 1904; personal communication from Prof. J. H. L. Vogt, March 15, 1908.

[b] Several small specimens kindly loaned by Mr. Frank L. Hess, Geologist, U. S. Geol. Survey, Washington, D. C.

Microscopic character.—A thin section of the less rich rutile portion of the rock was examined under the microscope and found to consist of essentially feldspar, much rutile, some quartz, and a little ilmenite. No ferromagnesian silicate minerals were observed.

Feldspar is much the most abundant constituent and is composed chiefly of a soda plagioclase (albite-oligoclase) together with some microcline and orthoclase, the latter intergrown with a second feldspar (albite) as microperthite. Some of the feldspar anhedra show partial micropoikilitic structure developed from inclosures of other feldspar, quartz, and rutile. The feldspars are quite fresh though occasional small areas of colorless mica due to alteration occur. Partial peripheral granulation of a part of the feldspar and quartz was indicated, accompanied by slight bending of the lamellæ of several plagioclase individuals.

When calculated in the usual way from the chemical analysis of the rock given below, the composition of the feldspar content corresponds to:

Or	6.12
Ab	52.40
An	5.56
Ab_nAn_m ratio	9.4:1
Or-Ab_nAn_m ratio	1:9.5
Total plagioclase	57.96
Total feldspar	64.08

Rutile, the next most abundant mineral to feldspar, occurs in irregular, massive grains to small idiomorphic crystals. Some of the larger grains show partial crystal outline. It is deep red-brown, distinctly pleochroic, and frequently shows cleavage and twinning. Some ilmenite is associated with the rutile and, in some cases, exhibits slight alteration to leucoxene. A single small grain of pyrite was observed inclosed in one of rutile. Apparently the rutile does not show predilection for one rock mineral more than for another. It occurs entirely enveloped by feldspar, along the sutures of feldspar individuals and of feldspar and quartz, and penetrates for greater or less distance into their substance. The relations of the rutile to the rock minerals suggest that it crystallized from the magma as did the feldspar and quartz, and that the usual order of crystallization from the magma was observed. These relations are well shown in Pl. III, figs. 2 and 3, microphotographs of thin sections of the rock.

A thin section of the rutile-rich portion of the rock, representing probably the schlieren of Professor Brögger, was studied microscopically. It was composed essentially of rutile, together with biotite partly altered to chlorite, some anhedral grains of apatite, and an altered light-colored silicate mineral probably a potash-feldspar.

In reflected light the rutile is dark brown to gray with faint greenish tinge; in transmitted light it is pleochroic, usually shows good cleavage and twinning, is marked by irregular fractures, and shows some alteration peripherally and along fractures to leucoxene. Biotite of brown color, strongly pleochroic and partly altered to chlorite, is developed in aggregates of shreds having at times a radial arrangement or grouping. Inclosures of the silicate minerals, chiefly biotite, are noted in the rutile, and rutile granules are distributed through the silicate minerals—a relationship which apparently indicates contemporaneous crystallization of the rutile and silicate minerals.

An analysis of rutile separated from the rock and freed as nearly as possible of silicate minerals yielded the following results:

Analysis of kragerite rutile from Kragerö, Norway.

(Wm. M. Thornton, Jr., *Analyst.*)

	Per cent.
TiO_2	97.68
SiO_2	1.06
FeO	0.81
Cr_2O_3	0.39
V_2O_3	0.55
Total	100.49
Specific gravity (J. W. Watson)	4.225

Chemical composition and classification.—This rock was analyzed by J. Wilbur Watson in the laboratories of the University of Virginia with the following result:

Analysis of kragerite (rutile aplite) from Kragerö, Norway.

(J. W. Watson, *Analyst.*)

	Per cent.	Mol.
SiO_2	50.52	.842
Al_2O_3	13.98	.137
Fe_2O_3	0.49	.003
FeO	0.16	.002
MgO	0.34	.009
CaO	1.05	.020
Na_2O	6.18	.100
K_2O	1.00	.011
H_2O-	0.20	....
H_2O+	0.30	....
TiO_2	25.00	.313
P_2O_5	Trace	....
V_2O_3	n. d.	....
MnO	None	....
CO_2	None	....
S	0.12	.003
Total	99.13	

A noteworthy feature of the rock as indicated in the analysis is the unusually large percentage of TiO_2 which is present chiefly as rutile and to a minor extent ilmenite. The high Na_2O, which greatly exceeds K_2O in amount, and the low CaO confirm the microscopic study of the composition of the principal feldspar, as corresponding to a sodic plagioclase of the albite-oligoclase series.

The norm as calculated from the analysis and the position of the rock in the quantitative system are as follows:

Norm of kragerite (rutile aplite) from Kragerö, Norway.

Quartz	7.62	
Orthoclase	6.12	
Albite	52.40	Sal = 72.31
Anorthite	5.56	
Corundum	0.61	
Hypersthene	0.90	
Hematite	0.48	
Rutile	25.04	Fem = 26.66
Pyrite	0.24	
H_2O	0.50	
Total	99.47	

The norm places the rock in the quantitative system in the dosalane class (II), in the germanare order ('5), in the domalkalic rang ('2) *monzonase,* and in the persodic subrang ('5). It is necessary to further subdivide into grad and section in order to show up the peculiar composition of the rock. This further subdivision places it in grad 5 permitic and section 5. This last subdivision (section) is not provided for rocks in class II (dosalane) of the new system.

The rock is a persodic monzonase but no subrang name has been proposed for the four known representatives of the persodic subrang of monzonase, neither analysis of which shows the peculiarities of composition of the Norway rock. Since the rock occupies an intermediate position in the quantitative system and on account of its unusual composition no name for the magmatic division is suggested.

GEOLOGY AND ORE DEPOSITS OF THE AMHERST-NELSON COUNTIES REGION.

LOCATION.

The rutile area of Amherst and Nelson counties, Virginia, lies in the west-central part of the State slightly northwest of the geographical center, and is about halfway between Charlottesville and Lynchburg. It occupies the south-central and southwestern parts of Nelson County, and the contiguous northeastern portion of Amherst County, but much the largest part of the area, and probably all that will prove of economic value in so far as rutile is concerned, lies in Nelson County, which includes all developments thus far made.

The area is approximately paralleled by the Southern Railway which is located at a distance varying from 5 to 7 miles to the southeast, Arrington and Tye River, the two nearest stations, being the principal shipping points. The area mapped includes approximately 170 square miles and is rectangular in shape, being 16 miles long by 10½ miles wide, with the rutile-bearing formation covering less than one-fifth of the total area. Its position is shown in the index, map, fig. 2. The rutile-bearing rocks are limited to this area and are confined to the northwestern half (Pl. I). The Southern Railway runs along the southeast side and just within the boundary of the map.

With reference to the major physiographic divisions of the State, the rutile area is located along the northwestern edge of the Piedmont Plateau, within the outlying foothills of the Blue Ridge, and almost directly at the foot of the steeper slopes to the main range. It lies wholly within the region of old crystalline rocks of the eastern United States extending from Maine to Alabama. The rocks included within the area mapped are regarded as igneous in origin.

DISTRICTS (SUBDIVISIONS).

The area mapped may be divided into three districts, named and their limits defined, as follows:

I. The *Roseland district* which extends as a long, narrow belt from a point about 2 miles northeast of Bryant, Nelson County, in a southwest direction across Piney River into Amherst County, a total length of 13 miles and a maximum width of about 2.5 miles. Roseland Post-office, from which the district derives its name, is located near the entrance of Hat Creek into Tye River, approximately halfway between the northeast and southwest extremities of the district.

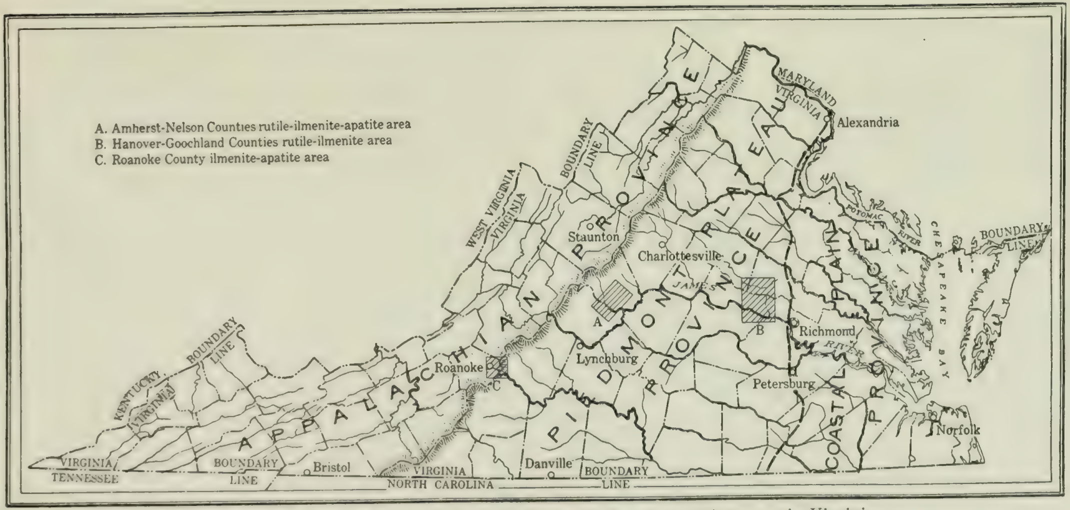

Fig. 2.—Index map showing position of the rutile-ilmenite-apatite areas in Virginia.

II. The *Lovingston district* which has no definite boundaries but comprises an area about 4 miles long by 2 miles wide, with Lovingston, the county seat of Nelson County, located near the middle of the east side of the district.

III. The *Davis Creek district* which is located on the north side of Davis Creek, and in some respects is similar geologically to the Lovingston district but of smaller areal extent.

This threefold division of the region offers certain advantages, but it is only partly followed in the method of treatment in the succeeding pages. In the Lovingston district certain rock types that are found are described on pages 198-201.

TOPOGRAPHY.

A reconnaissance topographic map of the area, adopted from the Buckingham and Lexington sheets of the United States Geological Survey, with the rutile-bearing formation outlined in heavy broken lines. is given on page 45, fig. 3. The map serves to indicate in a general way the relations of the larger topographic features of the area to the belt of rutile-bearing rock. This belt extends in a general northeast-southwest direction for approximately 16 miles, while the greatest width does not exceed 2.5 miles.

It occupies an area of comparatively low relief having an average elevation of about 800 feet, while the surrounding country immediately to the north, east, and west, rises to an elevation of from 1,400 to 1,500 feet except where the rivers and larger streams have incised their valleys. The only elevation of importance found within the low-lying, rutile-bearing formation is Mars Mountain, which has an elevation of a little over 1,500 feet; but this mountain, geologically as well as physiographically, belongs with the surrounding country with which it is probably connected. Passing northeast from the area mapped the hills become slightly higher, reaching an average elevation of 2,000 feet or more, while on the northwest, within 5 miles of the rutile-bearing area, outlying peaks of the Blue Ridge rise to altitudes ranging from 3,000 to more than 4,000 feet.

Tye and Piney rivers drain the central and largest part of the area; Buffalo River and its northeast tributaries drain the extreme southwest portion, while a small section around Lovingston occupying the northeast part of the area is drained by Rucker's Run. The general direction of drainage is toward the southeast into James River, the only important exception being Hat Creek, which drains the northeast end of the rutile belt and flows southwest into Tye River.

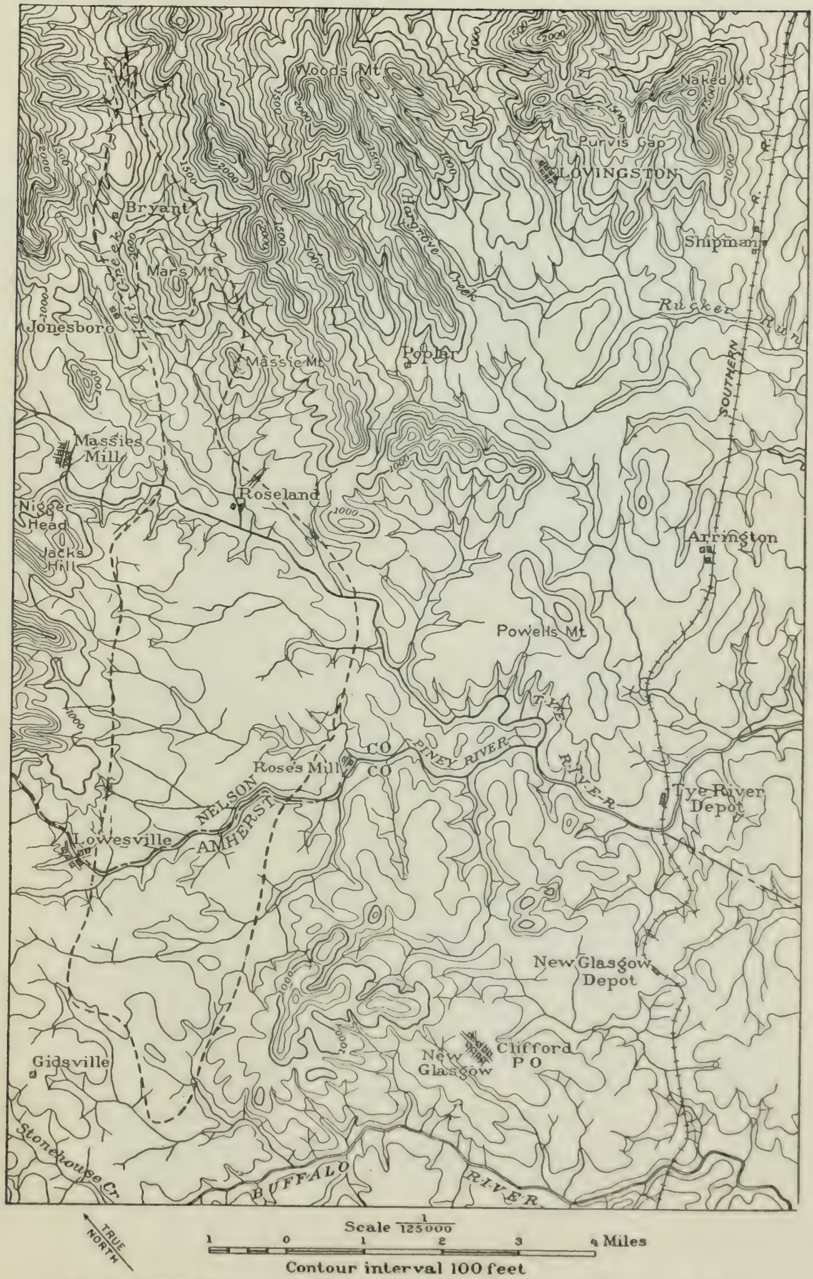

Fig. 3.—Topographic map of the Amherst-Nelson counties rutile area. (Modified from the topographic sheets of the U. S. Geol. Survey.)

WEATHERING.

In this region as elsewhere in the Piedmont Plateau province of the Atlantic states erosion has not been sufficiently rapid to remove the products of rock decay formed by weathering. Most of the area is covered to a variable depth by a mantle of residual rock decay, and moderately fresh hard rock exposures are rare except in stream beds and along stream courses. This fact together with the intense metamorphism which all the rocks have undergone makes accurate mapping difficult, and in some places impossible.

The depth of residual rock decay varies considerably, but in places it extends to a depth of 30 feet and is possibly much deeper. A photograph taken 200 yards west of Lovingston (Pl. IV, fig. 1) shows the gradation of residual rock decay into the underlying, nearly fresh and hard biotite gneiss. Here near the foot of the mountain a deep gully has cut through the cover of rock decay, which at this point has a maximum depth of about 20 feet. Every gradation is shown from the soil at the surface to the fresh gneiss exposed in the bottom of the gully.

Alluvial soils are confined to the immediate vicinity of the rivers and one or two of the larger creeks, but they are in no place extensive for all the streams in this area have either moderate or steep gradients, and at present are transporting rather than depositing material.

Since practically all the soils are residual, their character and composition are directly due to the rocks from which they have been derived. One of the most noticeable features of the area is the white clay soil found over much of the central part of the rutile-bearing portion. This white clay forms a striking contrast to the deep red color of the soils surrounding the area, red being the prevailing shade over most of the Piedmont region. These white soils are residual clays derived by weathering from the decay of a highly feldspathic rock (syenite) that is practically free from iron-bearing minerals except along border positions. Near the borders of the rutile-bearing rock (syenite) the soil is often found unusually highly colored with ferric oxide, due to the segregation of iron-bearing minerals, principally pyroxene and its alteration product hornblende, in this portion of the underlying rock-mass. The color of the soils surrounding the area, which are mostly derived from quartz monzonite gneiss, is primarily due to iron set free as oxide by the decay of black mica, biotite.

As shown by the analyses on pages 204-206 all the rocks in this region average high in phosphoric acid, ranging from about 0.50 per cent P_2O_5

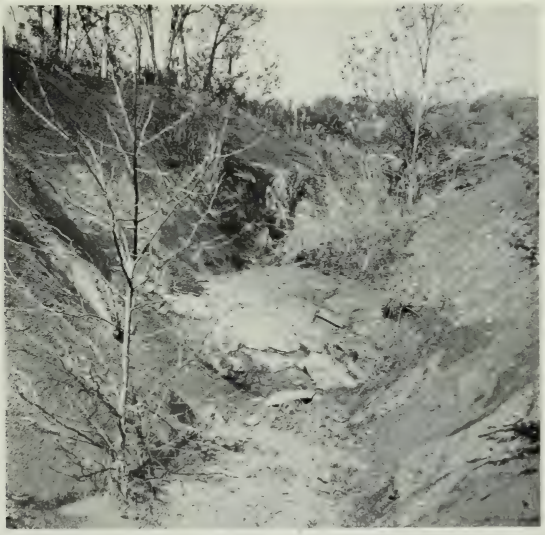

Fig. 1.—Granite-gneiss overlain by mantle of residual rock decay, 200 yards west of Lovingston.

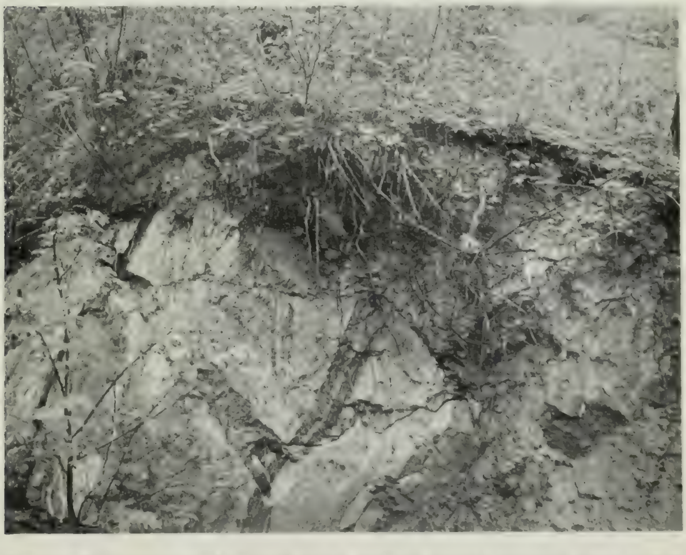

Fig. 2.—Gulley cut in residual rock decay exposing complex structure along contact between syenite and gneiss; 0.5 mile south of General Electric Company's mine.

RESIDUAL ROCK DECAY.

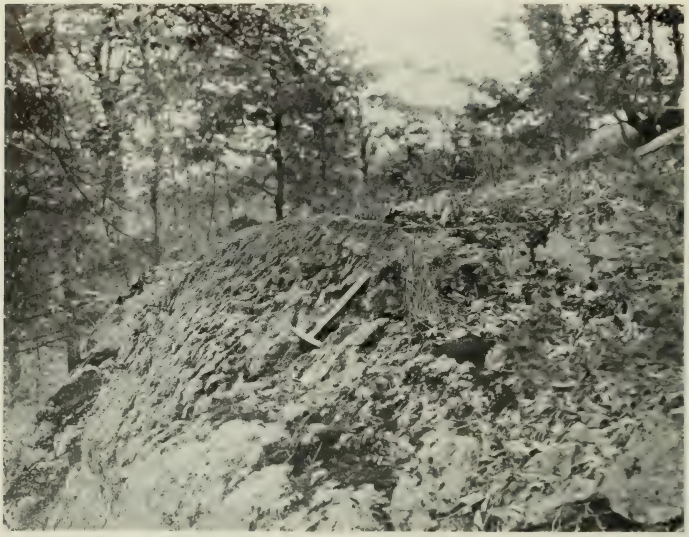

Fig. 1.—Banded syenite-gneiss exhibiting pronounced pitted surface from differential weathering. East bank of Tye River northwest of Roseland.

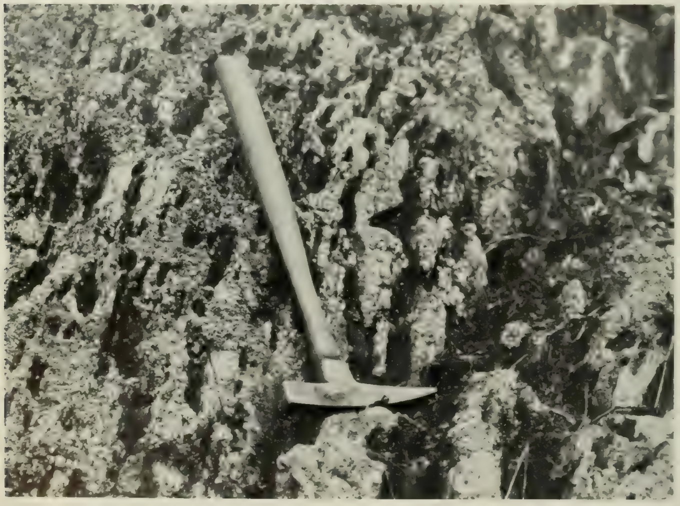

Fig. 2.—Detailed view of same exposure.

WEATHERED (PITTED) SURFACE OF SYENITE-GNEISS.

in the surrounding gneiss and 0.35 per cent in the syenite, up to 13 per cent in some of the nelsonite bodies. Largely because of this high phosphorus content the soils of this area are much more fertile than the average residual soil of the Piedmont province. Indeed the fertility of the soils of this district is in marked contrast to much of that of the neighboring country.

Because of the marked difference in resistance to weathering shown by some of the minerals locally important as rock-forming constituents, the rocks within the rutile area frequently exhibit noteworthy examples of differential weathering. The commonest form of differential weathering is noted in the nelsonites. Wherever the nelsonite rocks have been exposed for any considerable time at the surface the apatite has been readily removed through solution by meteoric waters, leaving the more resistant ilmenite and rutile of the rock in the form of a cellular or spongelike mass. Plate XII, fig. 2, shows a piece of weathered ilmenite nelsonite picked up on the surface of the Warwick tract, 1.5 miles northwest of Rose's Mill, which illustrates the typical weathering of nelsonite. Likewise the gabbro-nelsonites usually show similar pitted surfaces from weathering. A peculiar occurrence of large crystals of apatite in the syenite and its resultant weathering is described under syenite on page 81.

A second type of differential weathering in the district is shown (Pl. V, figs. 1 and 2) in some exposures of syenite in the bluff on the east side of Tye River, three-quarters of a mile northwest of Roseland. Here the rock is honeycombed with irregular cavities ranging up to 7 or 8 inches in length, 2 inches in width, and 3 inches in depth, but averaging about 3 inches long by three-quarters of an inch wide and 1.5 inches deep. These cavities are parallel to the schistosity of the rock which has a strike of S. 55° W. and dips northwest at an angle of about 70 degrees. The rock at this locality is composed almost entirely of feldspars and blue quartz, the latter occurring in long drawn-out thin lenses and irregular grains. The cavities are apparently due to kaolinization and removal of the feldspar.

HISTORY OF MINING.

At many places in the district ilmenite is found scattered over the surface as sand, or in loose masses varying in size up to a quarter of a ton or more. These loose rock masses, which have resulted from weathering of nelsonite dikes rich in ilmenite, are black, have a metallic lustre, and are usually pitted by reason of the removal by solution of apatite. They early attracted attention and were locally known as iron stones, but there is no record of any attempt to make use of this material until 1878, when the Philadelphia and Reading Coal and Iron Company purchased the Warwick farm 1.5 miles northwest of Rose's Mill, and the mineral rights on the Blue Rock farm 2 miles northeast of Roseland.

It was the intention of this company to work the properties for iron, and development work was begun on the Warwick farm where a shaft was sunk to expose one of the large nelsonite bodies outcropping on the south side of Piney River, in Amherst County, but this work was soon abandoned. On December 1, 1896, title to both properties was transferred to the Reading Iron Company. Nothing further was done in the district until attention was again drawn to the nelsonite bodies because of their phosphatic content.

In 1889, the Virginia Mining and Manufacturing Company acquired mineral rights to several properties in the vicinity of Bryant Post-office on Hat Creek and began development work. About 300 yards northeast of the Post-office a vertical shaft was sunk on an apatite-ilmenite (nelsonite) body to a depth of about 60 feet, and the dike was proved by numerous trenches for a distance of 600 yards along the strike. At the same time pits and trenches were dug wherever there were surface indications, and many ore-bodies were uncovered.

On the Camden farm, about 2 miles northeast of Bryant, a tunnel about 200 yards long was driven to cut one of the nelsonite bodies. On Davis Creek several shafts and tunnels were driven, but it is reported that the ore-bodies opened were small and low in the percentage of apatite. At this date all workings have caved and nothing is to be seen on the surface. After accomplishing a large amount of development work the Virginia Mining and Manufacturing Company failed and the property owners finally recovered title to the mineral rights by suit.

In April, 1894, the Virginia Phosphate and Paint Corporation purchased the Giles tract, three-quarters of a mile northwest of Roseland, and a year later the Quinn place, one mile north of Rose's Mill. Both of these properties were developed by means of trenches, pits, and shafts, and on the Giles tract a number of diamond drill holes were bored to ascertain the size and quality of the ore-bodies. It was the intention of this company to make a separation of the apatite and ilmenite, using the former for fertilizers and the latter in the manufacture of paint, but thus far no work has been done on a commercial scale.

In 1903, the W. M. Camp Phosphate Company purchased the Shelton farm which lies on the west side of Tye River, one mile above Roseland,

and soon after obtained the mineral rights to many other properties lying between Bryant and Rose's Mill. Most of these properties were developed by means of surface cuts, but no work was done other than to expose the ore-bodies. These properties were transferred to the Nelson Mining and Manufacturing Corporation in November, 1907.

In the Lovingston district as in the vicinity of Roseland the first prospecting was for iron. On the Whitehead and Bradshaw farms, 1.5 miles southeast of Lovingston, there are some small pits which are reported to have been opened about 40 years ago. These pits exposed nelsonite bodies carrying titaniferous magnetite and apatite.

During the past few years there has been much prospecting for phosphate rock and some development work has resulted, especially on the Dillard farm where several shafts were sunk. A number of car-load shipments of phosphate rock were made from this place, but in 1907 the property was sold to the American Phosphate Mining Company, and since then no work has been done. The mineral rights to several other properties in this district have recently been sold, but almost no development work has been undertaken to ascertain what they contain.

The occurrence of rutile in the Amherst-Nelson counties region has been known for many years and, while specimens picked up on the surface were sometimes sold, no attempt was made to exploit the rutile-bearing deposits of the district until 1900. In this year the American Rutile Company began operations on the east side of Tye River, a quarter of a mile south of Roseland, where rutile occurs as disseminated grains in the hard rock syenite, and several shipments of the ore were made to Charlotte, North Carolina, for concentration. In 1902, the company purchased the property and erected a stamp mill for crushing and concentrating the ore, which was mined entirely from open cuts in the bluffs near the east side of the river.

The ore, of which there is a large quantity in sight, probably averages about 5 per cent of the rock, and is remarkably pure. The rocks on this property, as well as over the district in general, are covered by a varying depth of residual rock decay which contains large quantities of rutile in places, especially in the soil overlying the ore-bodies. Some of these residual deposits could undoubtedly be worked to advantage by hydraulic mining, as there is usually an abundance of water close at hand. Since the above property was opened the Nelson County deposits have supplied all the rutile used in this country, and much of the output has been shipped abroad, but the demand has been limited and not sufficient to keep the mill in continuous operation. In 1907, the company purchased the Hubard tract on the opposite side of Tye River.

The General Electric Company entered the district in 1907, and, after prospecting several properties for rutile, began active development of some rutile-bearing nelsonite bodies on the Warwick farm 1.5 miles northwest of Rose's Mill. The development work comprised several hundred feet of tunneling, including drifts, and two shafts, the deeper of which was sunk to a depth of 100 feet. In some places the rutile is very pure, but of darker color than the syenite rutile mined by the American Rutile Company; in others it grades into ilmenite. Rutile has not been found on this property in the syenite sufficiently segregated to be of workable grade. The ore has been mined by stoping and shipped to Allentown, Pennsylvania, for concentrating. In 1910, the General Electric Company leased and operated the mines and mill of the American Rutile Company for a part of the year. Since the expiration of the lease the property has been operated by the owner, the American Rutile Company, which is at present the only operator in the district.

The syenitic rock of the Roseland district is often free from iron-bearing minerals, and weathers to a remarkably pure white kaolin. In 1890, the Pittsburg Kaolin Company erected a mill and drying plant on the Giles farm one mile north of Roseland. The kaolin was mined from surface cuts, dried in a steam dry-house, and separated from the small amount of quartz present by screening. It was packed for shipment in large paper sacks, and most of it was used as a filler in the manufacture of paper. After operating for about 5 years the plant was shut down because of a law suit among the stockholders, and since then it has not been in operation.

In 1907, the Saunders farm, 2 miles west of Claypool, was prospected for kaolin. Numerous auger holes were bored and it is reported that a very good grade of kaolin was found, but as yet no development work has been undertaken.

PRODUCTION.

Practically the entire production of rutile in the Amherst-Nelson counties area has been from the American Rutile Company's quarries at Roseland. During the progress of development work by the General Electric Company of Schenectady, New York, on the Warwick tract 1.5 miles northwest of Rose's Mill, some ore was shipped to Pennsylvania for concentrating, but complete statistics[a] are not obtainable.

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[a] According to Mr. Frank L. Hess about 100 tons of rutile ore, containing 50 per cent TiO_2, were shipped to a Pennsylvania company in 1909 for concentrating and reported to have yielded 35 tons of concentrates, Min. Res. of the United States, 1909, pt. I, p. 586.

The American Rutile Company's concentrating mill at Roseland was completed in November, 1902, and the statistics of production given below date from the time the mill was put in operation, in 1903, to the close of the year 1912. Owing to the limited demand for rutile ore the mill has been operated only for a part of each year. The milled stock on hand at the close of 1910, from ore mined during that year, was sufficient to meet the demands of the market during the year 1911, hence there was no production for 1911, but operations were again resumed in 1912.

Through the courtesy of Mr. W. M. Slater, President of the American Rutile Company, we are enabled to give below the complete statistics of production by the company from the beginning of milling operations, in 1903, to the close of 1912.

Rutile[a] *produced in Nelson County, Virginia, by the American Rutile Company, 1903-1912.*

	Quantity *(Short Tons)*
1903	54
1904	43
1905	16
1906	41
1907	118
1908[b]	16
1909[c]	86
1910[d]	566
1911	(e)
1912[f]	275
Total	1,215

USES.

The rutile produced at present by the American Rutile Company, operating at Roseland, Nelson County, Virginia, and the only producer in the State in 1912, is used for a variety of purposes. It is used for making the alloy ferro-titanium for use in the manufacture of titanium steel chiefly as rails for railroads; for the manufacture of titanium electrodes of the "magnetite" arc lamp; for the ceramic trade; and in the manufacture of titanium salts for use in dyeing leather and textiles.

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[a] Rutile concentrates containing 75 to 98 per cent TiO_2.

[b] Twenty-seven tons of ilmenite concentrates were sold by the company.

[c] From Oct. 22d to Dec. 30th, 1909, the General Electric Company, leasing the quarries and mill of the American Rutile Company, produced 86 tons of rutile concentrates.

[d] From Jan. 1st to June 1st, 1910, the General Electric Company, operating the American Rutile Company's property at Roseland, produced 248 tons of rutile concentrates.

[e] There was no production in 1911, as the unsold concentrates on hand at the close of 1910 were ample for the demands of 1911.

[f] The company did not begin operations in 1912 until June, and in addition to the 275 short tons of rutile concentrates, averaging from 80 to 85 per cent TiO_2, produced 100 tons of ilmenite concentrates. The ilmenite was separated from the rutile by an electro-magnet, and is especially adapted for making ferro-titanium.

A full discussion of the uses of titanium is given on pages 270-289 of this report.

PRICES.

The prices paid for rutile range from $30.00 to $160.00 per short ton, according to purity and quantity. Higher prices are obtained for pulverized rutile and for extra pure grades of the mineral.

LITERATURE.

Knowledge of the occurrence of rutile in Virginia dates back many years, but publications relating thereto are comparatively few. With only one exception, the published references relating to the Virginia deposits are of recent date and have been contributed since 1900, when the exploiting of rutile in the State commenced. The published literature relating to the area therefore is small. Since the beginning of mining operations at Roseland, in 1900, by the American Rutile Company, and near Rose's Mill, in 1907, by the General Electric Company, a number of geologists have visited the area and published brief statements on the geologic and economic features, more especially of those parts of the area under development. Most of the published statements relate more to the economic than to the geologic features of the area. The bibliography below includes all known publications relating to the Virginia titanium-bearing areas, including Amherst and Nelson counties, Goochland and Hanover counties, and Roanoke County.

ANON. (Special Correspondent). Rutile Deposits of Virginia.

Mining and Scientific Press, 1909, vol. xcviii, p. 896.

Describes the occurrence of rutile and ilmenorutile on the property of the General Electric Company in dikes, composed of rutile and apatite, and of ilmenorutile and apatite, with a small amount of ilmenite occurring in both kinds of dikes, and at times some feldspar and a small amount of biotite. The dikes are stated to range up to 5 feet in thickness. Mentions the occurrence of ilmenite with apatite in similar dikes, and states that all cut large dikes of pegmatite which carry rutile; the ilmenite-apatite rock has been called "nelsonite" by Watson. The author refers to the rutile deposit worked by the American Rutile Company, at Roseland, as follows: "The rutile occurs as an original constituent of a broad pegmatite dike of the same variety as that which forms the country rock on the General Electric Company's property at Rose's Mill, and is sufficiently segregated to be workable. The other minerals contained in the dike are albite (forming much the greater part of the rock), bright blue quartz, hornblende, and minor amount of apatite. A small percentage of the concentrate is ilmenite and ilmenorutile."

CATLETT, CHARLES. Occurrence of Rutile in Virginia. Discussion of Paper by T. L. Watson.

Economic Geology, 1907, vol. ii, pp. 796-797. .

Under the heading "Discussion," in Economic Geology, 1907, Mr. Catlett briefly notes the occurrence of mixtures of rutile with apatite, and of magnetite and apatite, in the Nelson County area. At times the magnetite is replaced by ilmenite. He says: "The occurrence is very peculiar in view of the extreme difficulty of separating titanium and phosphorus in ordinary chemical operations" (p. 797).

HESS, FRANK L. Nickel, Cobalt, Tungsten, Vanadium, Molybdenum, Titanium, Etc.

Mineral Resources of the United States, U. S. Geol. Survey, 1906, pp. 529-531; Ibid., 1907, Part I, pp. 720-721; Ibid., 1908, Part I, pp. 742-745; Ibid. for 1909, Part I, p. 586; Ibid. for 1910, Part I, pp. 762-763.

Describes the general geologic and economic features of the pegmatite rutile mined near Roseland, by the American Rutile Company, and of the nelsonite rutile occurring near Rose's Mill, under development by the General Electric Company. The author mentions the occurrence of ilmenorutile in some of the nelsonite dikes in the Nelson County area. He defines ilmenorutile as used by him as "a mineral containing too much iron to be classed as rutile and too much titanium to be classed as ilmenite." Gives statistics of rutile production.

HESS, FRANK L. New Rutile Deposits near Richmond, Va.

The Mining World, Aug. 20, 1910, pp. 305-307. Illustrated, 2 line-drawings and 2 half-tones.

The rutile deposits described were examined by the author in May, 1910, and are located, one in Hanover County near Gouldin, the other in Goochland County near Peers, distant 25 and 17 miles, respectively, from Richmond. The country rock is gneiss of variable composition, containing in many places much biotite and hornblende, with about equal quantities of feldspar and quartz. In places the gneiss is made up almost entirely of white feldspar. The strike of the rocks is north and south. The gneiss is cut by pegmatite dikes, the pegmatite usually lying between the structure planes of the gneiss, and was believed to have been intruded under great pressure. Both gneiss and pegmatite are decomposed for many feet below the surface.

Rutile occurs on the surface in loose grains and large pieces weighing 15 to 20 pounds on the Bowe farm and 200 to 300 pounds on the Nuchols farm, and as dots and streaks of reddish rutile in association with ilmenite in the pegmatite dikes. The rutile is associated with ilmenite, and some apatite occurs with the rutile and ilmenite. Rutile and ilmenite occur in stringers ½- to ¾-inch thick, in close relation to streaks of biotite mica. "The various narrow bands and stringers in the pegmatite may represent in part original flow structure, but are also due to later crushing. The whole dike has been crushed until it has taken on something of the gneissoid appearance of the surrounding rocks. The quartz has been recemented and is comparatively solid, but the rutile is in angular fragments and has not been recemented. There is some hydrous iron oxide which appears to have been formed from the decomposition of pyrite. In the more southerly of the prospect holes, which are only 15 feet apart, the rutile occurs in thin stringers throughout the width of the dike. The stringers are about ½ inch or less thick, and about 2 to 3 inches apart." The author mentions "aggregations of peculiar blue quartz with ilmenite and plagioclase feldspar, similar to the minerals accompanying rutile in the deposits at Roseland." Prospecting, in the nature of shallow shafts, pits, and trenches for rutile, has been carried on at several places. A brief statement of the uses of rutile concludes the paper.

MERRILL, GEORGE P. Rutile Mining in Virginia.

Eng. and Mng. Jour., 1902, vol. 78, p. 351; Abstract, Science, 1902 (n. s. 1), vol. xv, p. 389; The Nonmetallic Minerals, New York, 1904, pp. 109-110.

Describes the location of the rutile deposits on both sides of Tye River in the vicinity of Roseland, and the lithologic characters of the rocks, including the country rock, foliated gneiss, the rutile-bearing quartz-feldspar rock, and the dikes of hypersthene diabase. The author describes the rutile-bearing rock as follows:

"The petrographic character of the rock is very interesting. The most common type, as already stated, is a coarsely crystalline aggregate of potash and soda-lime feldspars of a very light gray, almost white, color, throughout which are disseminated the small rutiles like the phenocrysts of quartz in the Chalk Mountain, Colorado, Nevadite, as described by Dr. Whitman Cross. With this is associated a peculiar bluish opalescent quartz which, however, occurs under such conditions as to suggest that it is not a result of primary crystallization. Occasionally, as at the opening at present being worked, the quartz predominated over all other constituents, and masses of several tons' weight are procured in which the rutile granules occur in quantities up to 25 per cent of the entire mass. The rock is remarkably free from other minerals than those mentioned, with the exception of microscopic inclosures of sericite resulting from the feldspathic alteration. There is a complete absence of titaniferous iron or other heavy minerals such as would render difficult a separation of the rutile by ordinary gravimetric methods."

Regarding the occurrence of the ore, rutile, he says: "The ore occurs mainly in the form of small granules of all sizes up to 2 or 3 millimeters in diameter, which are sometimes disseminated with wonderful uniformity throughout the feldspathic groundmass or again segregated in the quartz."

MERRILL, GEORGE P. The Nonmetallic Minerals.

New York, 1904, pp. 109-110.

Dr. Merrill briefly describes the Nelson County, Virginia, rutile deposits near Roseland, the description being essentially an abstract of his paper published in 1902, noted in the title above, and does not present any new facts.

PRATT, JOSEPH HYDE. The Steel Hardening Minerals.

Mineral Resources of the United States. U. S. Geol. Survey, 1903, p. 103; Ibid., 1905, p. 414.

The author makes brief mention of the occurrence of rutile near Roseland, in Nelson County, Virginia.

ROBERTSON, ROBERT. An Examination of Blue Quartz, from Nelson County, Virginia.

The Virginias, 1885, vol. vi, pp. 2-3. Reprinted from Chemical News, London, England.

The author briefly refers to the location, extent, and character of the rutile-bearing blue quartz-feldspar belt in Nelson County, locally known as the "kaolin belt." He describes the blue quartz and in explanation of the blue color says:

"A fragment was fused before the hot-blast blowpipe flame and retained its blue color. The pulverized mineral was digested in hydrochloric acid to remove all ferric oxide which might exist in these films, and then treated with hydrofluoric acid to remove all silica. The analyses presented the following composition:

Ferric oxide	0.539
Titanic oxide	0.069
Silica (by diff.)	99.392

"A thin section of the rock was examined under the microscope and found to show throughout the mass a network of extremely thin acicular brown crystals, thus presenting, when magnified, about 400 diameters, an appearance very similar to that of sagenite to the naked eye. . . . This thin section is decidedly yellow by transmitted light, . . . and by reflected light is blue.

"In view of the color of some varieties of titanic oxide when seen by reflected light, it appears probable that the partial reflection of light by the surfaces of these microscopic crystals occasions the color in question, or the latter may be in a measure due to the interference of light occasioned by these crystals."

The author refers to the belt as one of granulitic rocks, and states that frequently masses of rutile are shown on the surface which have weathered out on decomposition.

SNELLING, W. O. Titanium Ores.

Mineral Resources of the United States, U. S. Geol. Survey, 1901, pp. 271-278; for Virginia, see pp. 277-278.

The author refers to the occurrence of rutile in Virginia and quotes at length from a paper read by Dr. George P. Merrill before the Geological Society of Washington in describing the geological features of the Virginia rutile deposits. He mentions the quality of the rutile as being excellent and very pure, and the supply as practically unlimited. The production commenced in 1900, and to the close of 1901 the output was about 40,000 pounds

THORNTON, WM. M., JR. A Feldspar Aggregate Occurring in Nelson County, Virginia.

Amer. Jour. Sci., 1911, vol. xxxi, pp. 218-220.

Gives an analysis each of nelsonite and feldspathic facies of syenite collected by Watson and Taber and analyzed for this report.

WATSON, THOMAS L. Occurrence of Rutile in Virginia.

Economic Geology, 1907, vol. ii, pp. 493-504.

The author differentiates and describes the lithologic and petrographic types of rocks, except nelsonite, in the Nelson County rutile area. Only the pegmatite occurrence of the rutile was described, which includes both megascopic and microscopic description, accompanied by map and four figures of microphotographs of thin sections. He says: "Rutile, in grains of variable size and in crystals of remarkable purity, varies in the rock from scant disseminations up to 30 per cent and more of the total rock mass, with a probable average of 10 per cent. It is disseminated through each of the three rock-forming minerals, feldspar, quartz, and hornblende. From mode of occurrence and textural relations of the rutile to the rock-forming minerals, as shown both by megascopic and microscopic study, the rutile is believed to be a primary constituent. The only metallic associate is ilmenite, which is more common in the quartzose parts of the rock than in the feldspathic facies, but is never present in large amount."

WATSON, THOMAS L. Ilmenite; Menaccanite or Titanic Iron. Rutile. Nelsonite (Phosphate Rock).

Mineral Resources of Virginia, 1907, pp. 232-235, ilmenite and rutile; pp. 300-302, nelsonite (phosphate rock).

Describes the distribution, occurrence, and uses of rutile near Roseland, Nelson County, and the milling process for concentrating the ore (pp. 232-234); and the granular mixture of ilmenite and apatite (pp. 232, 300-302) occurring in the same area in Nelson County and in Roanoke County, for which he proposed the name "nelsonite." Illustrated.

WATSON, THOMAS L. Annual Report on the Mineral Production of Virginia During the Calendar Year 1908.

Va. Geol. Survey, Bull. No. I-A, 1909, Phosphate, pp. 128-129; Rutile, pp. 129-130.

A later but brief description of the apatite, ilmenite, and rutile deposits occurring in Nelson and Roanoke counties, Virginia. Two types of the rutile in Nelson County were distinguished. In the first type, designated pegmatite rutile, the rutile occurs chiefly as disseminated grains of variable size in a rock of very coarse- to medium-grained crystallization of feldspars and blue quartz with, in places, much hornblende. In the second type, designated nelsonite rutile, the rutile occurs in an even-granular rock, having dike-like characters, composed normally of ilmenite and apatite, with or without rutile.

WATSON, THOMAS L. Biennial Report on the Mineral Production of Virginia During the Calendar Years 1909 and 1910.

Va. Geol. Survey, Bull. No. VI, 1911, pp. 112-113 (phosphate), 113-115 (rutile).

Briefly describes the apatite, ilmenite, and rutile deposits in Amherst and Nelson counties, Roanoke County, and Goochland and Hanover counties. The rutile production is given.

WATSON, THOMAS L., AND TABER, STEPHEN. The Virginia Rutile Deposits.

Contributions to Economic Geology, Bull. No. 430, U. S. Geol. Survey, 1910, pp. 200-213 and two figures (maps).

The writers discuss the Virginia rutile area under the principal headings, Location, Topography, General Geology, Principal Rock Groups, Chemical Composition of the Rocks, The Rutile Ore, History of Mining Development, and Uses of Titanium.

The rocks in the rutile area are igneous in origin, are distinctly metamorphosed, and they form a distinct comagmatic area characterized by the prominence of apatite and the titanium minerals—ilmenite, rutile, and in a few places titaniferous magnetite; by a peculiar blue opalescent quartz; and by pyroxene (chiefly hypersthene) or secondary hornblende derived from the pyroxene as the dominant ferromagnesian mineral. Named in the probable order of their differentiation, the principal rock types of the area mapped are (1) metamorphic igneous gneiss, including schists; (2) pegmatite; (3) gabbro; (4) nelsonite; and (5) diabase. In places the rocks of types 2, 3, and 4 appear to be approximately contemporaneous. The lithologic and petrographic characters of each type are described, and a chemical analysis of each one given. Gabbro, nelsonite, and diabase are discussed as dike rocks. The two distinct types of rutile, pegmatite and nelsonite rutile, which occur in the district are described in some detail. The history of the mining development of the district is stated, and the uses of titanium are discussed at some length. These uses are classified as follows:

Metallic alloys, such as ferro-titanium, cupro-titanium, etc.
Incandescent media for lighting purposes, including gas mantles, arc-lamp electrodes, and filaments for incandescent electric lamps.
Mordants and dyes for leather and textiles.
Refractory coloring material for use in ceramics and the manufacture of artificial teeth.
Miscellaneous.

Watson, Thomas L., and Taber, Stephen. Nelsonite a New Rock Type: Its Occurrence, Association, and Composition.

Abstract, Bull. Geol. Soc. Amer., 1910, vol. xxi, p. 787.

Watson, Thomas L., and Taber, Stephen. Igneous Complex of High Titanium-Phosphorus-Bearing Rocks of Amherst-Nelson Counties, Virginia.

Abstract, Bull. Geol. Soc. Amer., 1913, vol. xxiv.

Watson, Thomas L., and Taber, Stephen. Magmatic Names Proposed in the Quantitative System of Classification for Some New Rock Types in Virginia.

University of Virginia Publications, Bull. Phil. Soc., Sci. Ser., 1913, vol. i, No. 14, pp. 331-333.

Chemical analyses, norms, and symbols of four new rock types are reported, and appropriate magmatic names suggested by the writers.

GENERAL GEOLOGY AND PETROGRAPHY.

GENERAL STATEMENT.

The rocks in the Amherst-Nelson counties rutile district are igneous in origin, and are intensely but unequally metamorphosed. The different rock-types exhibit a marked relationship to one another in mineral as well as in chemical composition. By their mode of occurrence as well as by their consanguinity the rocks indicate that they had a common origin. They form a distinct comagmatic area characterized by the unusual prominence of apatite and the titanium minerals—ilmenite, ruile, and in a few places titaniferous magnetite; by a peculiar blue opalescent quartz; by pyroxene (chiefly hypersthene) or secondary hornblende derived from pyroxene as the dominant ferromagnesian mineral; and in most of the feldspar-bearing types by both potash and soda-lime species, the dominant variety of feldspar being a soda-lime plagioclase corresponding in composition to andesine, which frequently contains intergrown spindles of orthoclase (microcline)—andesine antiperthite.

Biotite, an important constituent in the surrounding gneisses and schists, is practically absent from the rocks within the rutile-bearing area. It occurs, however, as a minor constituent in some of the rocks and is generally present in the nelsonites, but its relations in some cases are such as to suggest probable secondary origin.

The rocks are holocrystalline in character and for the most part are even-granular, ranging from very coarse-grained in portions of the syenite to very fine-grained in some of the nelsonite and diabase dikes. They show pronounced though unequal effects of dynamic metamorphism, both in hand specimens and in thin sections under the microscope. Megascopically the most pronounced effect of metamorphism visible in most of the rocks is the development of complete or partial schistose structure, frequently accompanied by granulation of certain minerals, and by bent and curved cleavage lamellæ.

Microscopically, metamorphism is manifested chiefly in mashing—granulation, fractures, and optical disturbance of certain essential minerals—and sometimes in recrystallization. Other changes of a different order and kind involve the production of secondary minerals from the essential ones, chief among which is the formation of hornblende from pyroxene, leucoxene from the titanium minerals, rutile and ilmenite, osteolite from apatite, and sericite as a common alteration product from feldspar. In some of the rocks biotite, chlorite, epidote, and zoisite are noted as alteration products.

PRINCIPAL ROCK GROUPS.

The rocks of the mapped region are divisible into five distinct groups, but intermediate gradations are found between most of them. In general the dominant minerals in one type make up the minor accessory minerals in the others, but between some of the rock-types almost every gradation in mineral composition may be observed. Named in the order of their probable differentiation, including the surrounding rocks, the principal rock-types of the area mapped are as follows:

(1) Biotite-quartz monzonite-gneiss, and variant schists.
(2) Syenite formerly referred to as pegmatite.
(3) Gabbro.
(4) Nelsonite.
(5) Diabase.

In places the rocks of types 2, 3, and 4 appear to be approximately contemporaneous. Gabbro may be observed grading into syenite, and in places a gradation from the gneiss through gabbro into syenite is indicated; some of the rutile nelsonites have the appearance of segregations in the syenite rather than later differentiates that have been intruded; and while a gradation of gabbro into nelsonite in the same rock-mass was not found, nearly all intermediate gradations in mineral composition between the two rock-types occur in the district.

AREAL DISTRIBUTION.

The gneiss with its accompanying schists forms the inclosing or country rock of the region, and is of wide general distribution beyond the limits of the rutile area throughout the Blue Ridge region of central western Virginia.

The syenite is chiefly confined to a single large mass, extending in a northeast-southwest direction for a distance of about 16 miles, with Roseland near its center. The maximum width of the syenite mass does not exceed 2.5 miles. At the northern end of this area the syenite appears to split up and dikes or apophyses are found extending outward for some distance into the country gneiss. The boundaries of the syenite area are shown on the topographic map, fig. 3, page 45, and in greater detail on the geological map of the district (Pl. I). Small pegmatite and aplite dikes are of numerous occurrence in the vicinity of Lovingston, and a few were observed near the headwaters of Davis Creek about 5 miles northwest of Lovingston.

Exposures of the gabbro are found for the most part only within the boundaries of the large syenite area, but a few gabbro dikes were observed near Lovingston. Within the syenite area the gabbro is mostly limited to the outer portions and in places it apparently occurs as an intermediate gradation between the syenite and gneiss. There are, however, other occurrences where gabbro in dikelike masses cuts the older syenite with sharp contacts. Because of the extensive residual rock decay which covers the rocks of the region to a variable depth, mapping of the gabbro with any degree of accuracy was found to be diffcult if not impossible; hence, differentiation between the gabbro and the syenite was not attempted in preparing the geological map (Pl. I).

Nelsonite, including several varieties based on differences in mineral composition, is the most abundant type of dike-rock occurring in the district. The rutile-bearing variety of nelsonite is confined to the syenite area, but the ilmenite nelsonite free from rutile, while more numerous within the syenite area, is also found in the gneiss near the contact, and occurs in the section around Lovingston and on Davis Creek. Nelsonite in which magnetite is a prominent constituent is found at several places in the surrounding gneiss, but does not occur in the syenite mass. All known outcrops of nelsonite are given on the geological map of the district (Pl. I).

Gabbro-nelsonite, including a group of rocks intermediate in mineral composition between gabbro and nelsonite, is found both in the Lovingston district and in the syenite area of the Roseland district. In the latter district they are found only within the syenite, usually in border positions.

The diabase dikes are the youngest rocks in the region. They cut all other formations, but are confined chiefly to the rutile-bearing rocks found within the large syenite area. They occur but are observed less frequently in the outside gneiss.

The five principal rock groups included within the area mapped are separately described in detail in the following pages in the order enumerated above.

Biotite-Quartz Monzonite-Gneiss.

DISTRIBUTION AND LITHOLOGIC CHARACTERS.

Distribution.—The outside or country rock of the rutile-ilmenite-apatite area is a pronounced foliated, quartz-biotite gneiss, which shows in many places a considerable development of schists of variant composition. Gneiss is the dominant type in this complex of metamorphic rocks and has wide general distribution beyond the limits of the area mapped throughout the Blue Ridge region of central western Virginia. Its distribution within the area mapped is shown on map, Pl. I.

Lithologic characters.—The gneiss has a pronounced banded or schistose structure and exhibits considerable textural and mineralogical variations, but the prevailing kind is a medium to dark gray rock varying from a fine- to medium-coarse, even-granular to porphyritic texture, the rock having in the latter case a distinct augen-gneiss appearance. The planes of schistosity vary from moderately irregular foliation in the original porphyritic facies of the rock, where the biotite is wrapped about the lenticular eyes of feldspar, to banding that is more or less regular and continuous, and ranging from very thin to relatively thick layers. The strike of schistosity of the gneiss in the Lovingston district is quite uniform, varying rarely more than a few degrees from N. 40° E. In the Roseland district good exposures of the gneiss are less frequent, but where measured the strike conforms in general with that of the Lovingston district.

The original porphyritic texture which characterized certain parts of the gneiss is still readily recognized, and the feldspar phenocrysts plainly show the effects of pressure metamorphism. In places the feldspar crystals are drawn out and inclosed between the biotite layers forming distinct "augen" of the light-colored minerals, and may contain inclosures of the ground-mass quartz and biotite. The field and microscopic evidence clearly indicate that the schistose structure of the gneiss is secondary, induced by dynamo-regional metamorphism, and not a primary or original structure as has been recently advocated for some gneisses elsewhere.

The gneiss is derived from an original igneous rock as is indicated by the field, microscopic, and chemical evidence. The principal minerals recognizable with the naked eye are feldspar, quartz, and biotite. Ilmenite and muscovite, and rarely hornblende, are also apparent in some specimens. The former (ilmenite) is frequently concentrated in the sands derived from the decay of the gneiss. Some of the black grains composing the sand are magnetic and are probably magnetite. Biotite is frequently altered to chlorite, and in the vicinity of the gneiss-syenite contact much of the quartz in the gneiss is pale blue in color, resembling that of the syenite. Epidote has been observed in one or two instances forming a thin veinlet of less than 1 mm. in thickness. Occasional masses of amphibolite schist are observed in the gneiss. Such an occurrence is noted about half a mile north of Jonesboro, where amphibolite schist is exposed within the gneiss, but not far from its contact with the syenite.

Segregations (schlieren), chiefly basic and usually composed largely of biotite, occur here and there in the gneiss. They are roughly oval in outline to those that are greatly elongated (lens-shaped), and are usually of small though variable size. Several lenticular masses included in the gneiss are exposed by blasting for the county road three-quarters of a mile north of Lovingston. Some of these resemble diabase while others seem to be composed almost entirely of feldspar.

Dikes of acid (granite and pegmatite) and basic (diabase) rocks intrude the gneiss in places. Granite and pegmatite dikes are especially noted in the Lovingston district and are described in some detail on pages 200-201. Diabase dikes are confined chiefly to the rutile-bearing rocks, but are observed here and there beyond these limits penetrating the surrounding gneiss on the southeast side of the Roseland district. These are found in place near the contact at Rose's Mill (analysis IV, page 158) and along the road leading to Amherst Courthouse. About 2 miles northwest of Lovingston diabase float occurs, but the rock has not been observed in place.

Veins of white quartz intersecting the gneiss are numerous along the northwest border of the syenite. Some of these are quite large, ranging up to 75 feet and more in cross-section, and may be traced in the direction of strike for considerable distances. These veins rarely occur in the gneiss on the southeast side of the area, and they become much less frequent some distance from the contact on the northwest side.

MICROSCOPIC CHARACTER.

The exact mineralogical composition of the rock detailed in this description is the dominant or prevailing type of the outside biotite-quartz monzonite-gneiss. It is not possible to describe in detail the exact mineralogical composition of the various schists found here and there within the gneiss, for the reason that specimens sufficiently fresh to yield trustworthy results could not be obtained for the preparation of thin sections. The important textural and mineralogical variations are noted in the description above.

In thin sections the rock is a biotite-quartz monzonite-gneiss of granitic texture, varying from fine- to medium-coarse, even-granular to porphyritic, sometimes exhibiting a banded or foliated structure. The minerals are potash feldspar (orthoclase and microcline), soda-lime feldspar (albite-oligoclase and oligoclase), quartz, and biotite, together with accessory ilmenite, apatite, rutile, zircon, and occasional titanite and pyrite, and secondary chlorite, colorless mica (muscovite), epidote, kaolin, zoisite, calcite, and leucoxene. Thin sections of the weathered rock show considerable free iron oxide as a yellowish-brown stain.

An important feature in the mineral composition of this rock, as in the granites and granite-gneisses of the Southern Appalachians[a] in general, is its large content of plagioclase feldspar, which frequently equals in amount the potash feldspar (orthoclase and microcline), but the ratio varies for individual thin sections examined. Extinction angles measured against the twinning striæ usually indicate a plagioclase near oligoclase. This is confirmed by both the analyses below and the albite-anorthite ratio calculated from the two norms of the quartz monzonite-gneiss on page 65. In each case the norm shows a plagioclase corresponding approximately to Ab_2An_1 in composition, a calcic oligoclase.

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[a] Watson, Thomas L., Bull. No. 426, U. S. Geol. Survey, 1910, 282 pages. Bull. Philosophical Society, University of Virginia Publications, 1910. Scientific Series, vol. i, No. 1, pp. 1-40.

Some thin sections show a part of the plagioclase to be albite, probably through loss of calcium, as in each case the soda feldspar is more or less altered, partly to lime-bearing minerals as secondary products. Not infrequently the plagioclase lamellæ are bent and curved and often broken across from pressure effects. Microcline is variable in amount; in some thin sections it is the dominant feldspar, in others it fails entirely.

A thin section cut from a hand specimen (32)[a] of the gneiss, about one mile N. 65° E. from Roseland, showed microcline with intergrown spindles of oligoclase to be the dominant feldspar. Also there occur a few crystals of plagioclase which are much altered but seem to be albite, probably from loss of calcium.

Intergrowths of microcline and orthoclase with plagioclase feldspar, as microperthite, are abundant, and of feldspar with quartz, as micropegmatite, sometimes occur. The larger feldspar individuals are usually micropoikilitic in texture, chiefly from inclosures of quartz and other feldspars. In addition to these the feldspars contain microscopic inclusions of other minerals, which are so abundant in some cases as to greatly cloud the feldspar substance. The exact nature of the inclusions was indeterminate; they include dustlike particles and larger colorless and transparent crystallites of prismatic and tabular habits to those of irregular outline, and are arranged in some thin sections along definite parallel lines. In those thin sections of less fresh rock the feldspar substance is almost entirely obscured from alteration products, chiefly colorless mica, kaolin, and epidote.

Quartz is the next most abundant mineral to feldspar and is chiefly colorless, but the pale blue variety is observed in some thin sections. It shows the effects of pressure metamorphism in granulation, fractures, and wavy extinction, and occasionally shows inclusions of rutile needles and of liquid and dustlike particles.

Biotite, the third essential constituent, is deep brown and strongly pleochroic, varies both in size of shred and in amount, and is partly altered to chlorite. It is distributed through the rock in long and stout shreds and aggregates with frequent orientation shown along roughly parallel directions (schistosity). Some blue-green hornblende is associated with the biotite in two of the thin sections (Nos. 33 and 196).

Apatite occurs as inclusions in the light-colored minerals, chiefly feldspar, and in several thin sections (Nos. 35, 36, and 218), as separate individual grains. Likewise rutile is noted as included needles in some of the quartz and sometimes as larger individual, reddish-brown grains (Nos. 23 and 36). A single thin section (No. 23) showed some fractured garnet and irregular areas of black graphite.

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[a] Numbers refer to hand specimens and thin sections on file at the office of the Virginia Geological Survey.

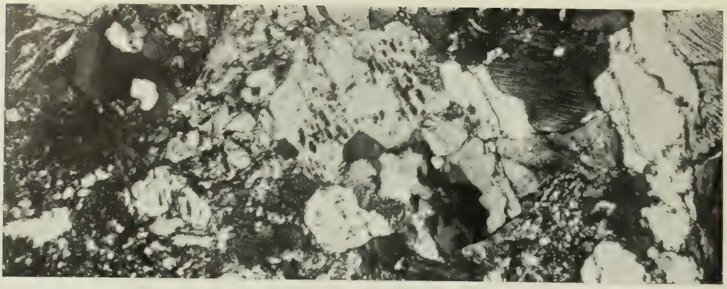

Fig. 1.—Biotite-quartz monzonite-gneiss near contact with syenite, 0.75 mile northeast of Roseland. Nicols crossed. Enlarged 30 diameters. Specimen No. 32.

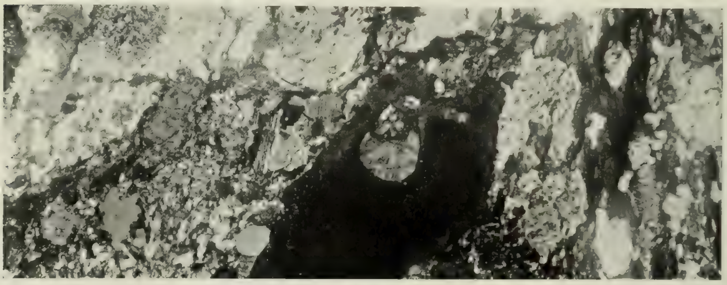

Fig. 2.—Biotite-quartz monzonite-gneiss, 1 mile north of A. G. Bryant's house, Nelson County, showing mashing from dynamic metamorphism. Nicols crossed. Enlarged 30 diameters. Specimen No. 73.

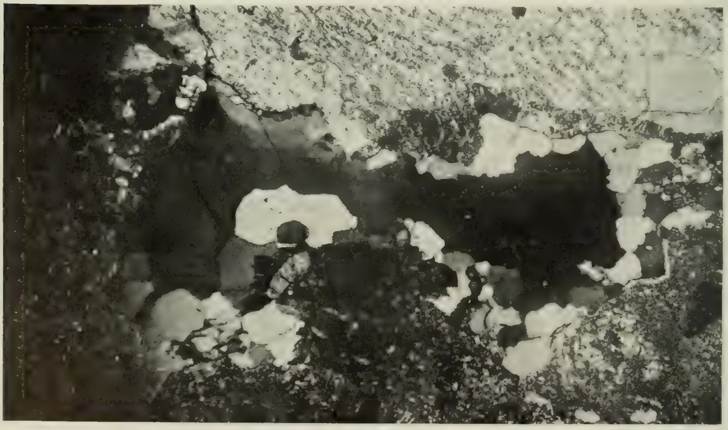

Fig. 3.—Biotite-quartz monzonite-gneiss, 3 miles north of Lovingston, showing granulation of quartz from dynamic metamorphism. Nicols crossed. Enlarged 30 diameters. Specimen No. 198.

PHOTOMICROGRAPHS OF BIOTITE-QUARTZ MONZONITE-GNEISS.

Specimens 23, 35, 36, and 218 are from points near the gneiss-syenite contact.

The effects of dynamic regional metamorphism are manifested in the foliated or schistose structure from the orientation of biotite and the granulation of the quartz and feldspar, in strain shadows and lines of fracture in the quartz and feldspar, and in many of the thin sections in the bent and often broken lamellæ of a part of the plagioclase. In some thin sections the larger feldspar grains are much fractured and the lines are filled with quartz and mica. Photomicrographs of the quartz monzonite-gneiss are shown in Pl. VI.

Individual descriptions of the gneiss from different localities in the region are given on pages 84-90 and 198-199.

CHEMICAL COMPOSITION AND CLASSIFICATION.

The chemical composition of the quartz-biotite monzonite-gneiss is shown in the two analyses given below, made on specimens collected from near Colleen and Lovingston, Nelson County, Virginia. The localities from which the specimens were collected, yielding the results on analysis shown in columns I and II, are on the southeast side of the rutile-bearing rocks and are separated by a distance of about 5.5 miles. Considering the variable character of the gneiss and the distance between the localities from which the specimens were collected, fairly close agreement is shown in the two analyses.

Analyses of biotite-quartz monzonite-gneiss from Nelson County, Virginia.
(WM. M. THORNTON, JR., *Analyst.*)

	I	II	III
SiO_2	63.40	66.46	64.93
Al_2O_3	15.94	14.92	15.44
Fe_2O_3	2.01	1.87	1.94
FeO	3.91	3.08	3.50
MgO	1.33	1.11	1.22
CaO	3.75	3.10	3.42
Na_2O	3.53	2.63	3.08
K_2O	3.30	4.74	4.02
H_2O-	0.06	0.06	0.06
H_2O+	0.76	0.80	0.78
TiO_2	1.33	0.83	1.08
P_2O_5	0.55	0.29	0.42
MnO	0.05	0.07	0.06
CO_2	Trace	Trace	Trace
S	Trace	Trace	Trace
	99.94	99.96	99.95
Specific gravity	2.82		

I. Quartz-biotite monzonite-gneiss, Arrington-Roseland road, 1 mile north of Colleen.
II. Quartz-biotite monzonite-gneiss, county road, 0.75 mile north of Lovingston.
III. Average of I and II.

A microscopic description of thin sections of the two rocks yielding the analyses above follows:

I (Spec. 213). In hand specimens the rock has a pronounced foliated structure, with feldspar "augen" (eyes) ranging up to 2 cm. in diameter. The principal minerals are feldspar (plagioclase near oligoclase, microcline, and orthoclase), quartz, and biotite, and the minor accessory constituents are apatite, rutile, and titanite. The secondary minerals include much colorless mica, chlorite, epidote, and leucoxene. Microcline and orthoclase are present in approximately equal amount, and combined they do not exceed plagioclase in quantity. They are developed in irregular tabular masses considerably altered to fine shreds of colorless mica; plagioclase shows characteristic albite twinning, the lamellæ of which are frequently bent and broken. Quartz forms distinct areas of fine-grained mosaics filling spaces between the feldspars, is fractured, shows wavy extinction, and contains inclusions of apatite, rutile, etc. Biotite shows its usual characters and is partly altered to chlorite. The effects of dynamic metamorphism are manifested in granulation of the feldspar and quartz, and in bent and broken lamellæ of plagioclase (oligoclase).

II (Spec. 182). Megascopically the rock is a typical coarse-grained, foliated, biotite gneiss exhibiting feldspar "augen" (eyes) 2 to 3 cm. in diameter. A thin section of the rock shows essentially the same mineral composition and relations as that described above (Spec. 213). The minerals are feldspar (orthoclase partly intergrown with plagioclase, microcline, and plagioclase near oligoclase), quartz containing inclusions of rutile needles and apatite, brown pleochroic biotite partly altered to chlorite, and occasional grains of apatite and zircon. The secondary minerals include colorless mica, chlorite, epidote, and leucoxene. The usual evidence of dynamic metamorphism is strongly shown in the thin section.

It is not possible to calculate from the analyses above the exact proportion of the ferromagnesian constituent in the quartz monzonite-gneiss, because of the fact that its composition is not definitely known. The norms,[a] calculated from analyses I and II, are given in the subjoined table, and in each case they approximate closely to the actual mineral composition (mode) of the rocks.

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[a] Norm is defined as the standard mineral composition of a rock; *i. e.*, the chemical composition expressed in terms of standard minerals. "A Quantitative Classification of Igneous Rocks," by Cross, Iddings, Pirsson, and Washington, University of Chicago Press, 1903.

Norms corresponding to analyses on page 63.

	I	II
Quartz	20.00	24.42
Orthoclase	19.46	27.80
Albite	29.87	22.01
Anorthite	15.29	13.62
Corundum	0.92	0.51
Hypersthene	6.60	5.84
Magnetite	3.02	2.55
Ilmenite	2.58	1.52
Apatite	1.24	0.62
Water	0.82	0.86
	99.80	99.75

The position of the rock in the quantitative system of classification is shown by the following symbols:

No.	Symbol.	Name.
I.	'II. 4. 2'. 3'.	Adamellose.
II.	I'. 4. 2'. 3.	Toscanose.

I is a sodipotassic dacase with the subrang name *adamellose,* and II is a sodipotassic toscanase with the subrang name *toscanose.*

The analyses indicate a rock of quartz monzonite character, which is best illustrated in the annexed table of feldspar composition, calculated from the two analyses above in the usual way.

Table of feldspar composition corresponding to analyses on page 63.

	I	II
Orthoclase	19.46	27.80
Albite	29.87	22.01
Anorthite	15.29	13.62
Total plagioclase	44.16	35.63
Total feldspar	64.62	63.43
Ab_nAn_m ratio	2:1	2:1
Or.-plag. ratio	1:2+	1:1+

Attention is directed in the analyses on page 63 to the more than appreciable percentages of TiO_2 and P_2O_5, each of the two constituents being above the usual average for rocks of this type, as shown in the comparison below with analyses of granites and granite-gneisses in general.

Of the 167 entries of granites and granite-gneisses in Washington's[a] list of superior analyses, nineteen, or 11 per cent, contain 0.50 per cent and more of TiO_2; seven, or 2.4 per cent, contain 0.75 per cent of TiO_2; and only two contain TiO_2 exceeding the minimum (Lovingston quartz monzonite-gneiss) percentage in the Nelson County rock (0.83 per cent). Only one (1.57 per cent) exceeds the maximum (1.33 per cent) and the average (1.08 per cent) percentages of TiO_2.

Likewise the same entries (167) show that ten, or 6 per cent, contain 0.25 per cent and more of P_2O_5; seven, or 4 per cent, contain more than 0.30 per cent of P_2O_5; and three, or less than 2 per cent, contain more P_2O_5 than is shown in the average (0.42 per cent) of the two analyses of quartz monzonite-gneiss from Nelson County.

Eight complete analyses[b] of the commercial grades of granites and gneisses in eastern Piedmont Virginia show the range in TiO_2 to be 0.20 to 0.50 per cent, with an average of 0.38 per cent, an amount nearly two and a half times lower than the minimum percentage of TiO_2 in the Nelson County quartz monzonite-gneiss (0.83 per cent), and the maximum of eight analyses (0.50 per cent) is much below the minimum of the two analyses of the Nelson County rock. The eight analyses show the range in P_2O_5 to be 0.02 to 0.49 per cent, with an average of 0.27 per cent, which is less than the minimum (0.29 per cent) of the two Nelson County rocks, and very much less than the average of these (0.42 per cent). However, four of the eight analyses show more P_2O_5 than the Lovingston rock (0.29 per cent), but only one of the eight shows more P_2O_5 than the average of the two analyses of gneiss from Nelson County.

QUARTZ VEINS.

Quartz veins of large and small dimensions are numerous in places within the area mapped. Veins of white quartz, usually free from other minerals, especially sulphides, are rather abundant in the outside gneiss along the northwest border of the syenite. Some of these are quite large, ranging up to 75 feet and more in thickness, and may be traced over the surface for considerable distances, usually in a northeast-southwest direction, partly by the disintegrated outcrops and the loose fragments which litter the surface. Very little white quartz is found within the syenite area but outside of its limits, especially on the northwest side, the loose fragments on the surface are very plentiful.

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[a] Washington, H. S., Professional Paper No. 14, U. S. Geol. Survey, 1904.
[b] Watson, Thomas L., Bulletin I-A, Va. Geol. Survey, 1909, p. 81.

Some of the veins contain quartz crystals which weather out and may be picked up on the surface. In several places the quartz crystals are violet in color, and on the farm of J. S. Saunders, 3.25 miles west of Claypool, many beautiful amethysts of gem grade have been obtained. About half an acre has been worked over by trenching to a depth of from 4 to 6 feet. The amethyst is found in residual red clay cut by small broken veins or stringers of white quartz striking in various directions. Occasionally pieces of feldspar more or less kaolinized are also found. The amethyst occurs in small pockets of variable size usually closely associated with the quartz stringers, hence it is generally customary in mining to follow the veinlets or stringers. Amethyst picked up on the surface, which has been exposed to sunlight for some time, is usually faded and of no value. The product from this mine is controlled at present by the American Pearl and Gem Company.

Many amethyst crystals have been picked up on the surface of the Stratton farm a mile southeast of Massie's Mill, and at a point about half a mile northeast of Fancy Hill, but at neither place has any prospecting been done.

Several quartz veins of small dimensions composed of blue opalescent quartz, which closely resembles in color the same constituent in the syenite, occur within the syenite area. It is probable that most of the blue quartz fragments found in large quantities at several places within the area is derived from veins, but because of the depth of rock decay they are not exposed.

About half a mile southwest of Bryant, a vein of blue quartz, containing a little pyrite and a second mineral too badly altered to be identified, crosses the road entering the farm of M. C. Massie. The vein is about 3 feet wide and trends S. 60° E. A similar vein of sky-blue quartz 1.5 feet wide is exposed on the north side of the county road one mile northeast of Bryant. Neither graphite nor sulphides were identified in the quartz of this vein. On the slope of Mars Mountain half a mile south of Bryant there is much blue quartz float which probably has been derived from a similar vein. It is a sky-blue opalescent quartz containing numerous disseminated flakes of graphite 2 to 3 mm. in diameter.

Under the microscope a thin section of the blue quartz showed inclusions of rutile, graphite, and minute dustlike particles, the exact nature of which could not be determined. The rutile inclusions consist of hairlike or needle forms and chains of perfect crystals of brown color with the longer axes usually oriented in the direction of the chain. Some crystals of rutile have the longer axis normal to this direction. The graphite is inclosed in the quartz as small, irregular areas composed of fine-granular material, and in such relation to the host as to indicate contemporaneous crystallization. Visible pressure effects are manifested in the quartz in partial granulation and optical disturbance.

Syenite.[a]

GENERAL STATEMENT.

This rock has been previously called pegmatite in former publications on the Amherst-Nelson counties area, but more detailed field and laboratory study of the rock mass as a whole suggests that it is probably not a normal pegmatite, but an intermediate type between a soda syenite and a less calcic anorthosite, with modifications in places along border positions. The principal reasons for this change may be briefly summarized as follows:

The textural relations of the feldspar and quartz to each other and of the hornblende when present are, over many parts of the rock mass, similar to those of a coarse pegmatite. The ratio of the essential minerals is subject to much variation as indicated in the description, but the changes from one kind to another are not so abrupt as to impose a marked heterogeneous texture through the entire rock mass. Many of the larger areas of anorthosite composed in general of little else than basic plagioclase (labradorite) exhibit very coarse textures and show frequent indications of gradation into gabbros.

With the exception of the titanium minerals, rutile and ilmenite, and occasionally of the phosphate, apatite, none of the numerous accessory and exceptional minerals occur, such as result frequently in the production of comb and ribbon or banded structures in true pegmatites; nor have miarolitic cavities been observed at any point. The absence of special minerals from this rock does not in itself constitute a valid argument against its being a pegmatite, since such minerals are by no means present in all pegmatites, especially in those of gabbros, as it is held by many geologists that the latter do not as a rule carry special minerals.[b]

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[a] Chemical and microscopical studies of the central and larger portion of this rock mass, composed chiefly of feldspar, indicate an intermediate rock type in character, with affinities which probably more closely ally it to anorthosite than to syenite. (See analyses on page 76, which are characterized by high CaO and Na_2O, but by a goodly amount of K_2O also, giving much normative orthoclase, 16.68 to 23.35 per cent.) The rock is described in this bulletin under the old classification name *syenite*, but since the principal feldspar is a calcic-soda variety (andesine) with intergrown orthoclase (microcline), the name *andesine-anorthosite* would define it more exactly.

[b] Harker, A., The Natural History of Igneous Rocks, 1910, p. 299.

No uniform decrease in granularity toward the walls is observed in the rock mass, although in many places around the border the contact is not entirely sharp, but is marked by gradual passage or merging of the rock into the bordering gabbro without demarkation, so that frequently a specimen taken from this position is difficult, indeed at times impossible, of classification, whether belonging to one or the other of the two types. Unfortunately the contacts over most of the area are obscured by the residual decay of the rocks, so that definite conclusions based on study of exposures are entirely limited to a few occurrences. Probably the best exposure is found on the property of the American Rutile Company extending southeastward from the mill near Roseland along the east side of Tye River. Gradation of the syenite on the southeast side into gneissic uralitic gabbro is indicated, but towards the west from the gradation zone the hornblendic or border facies of the rock mass shows very coarse granularity.

No evidence has been observed either in the field or in the microscopic study of thin sections indicating graphic intergrowths, so common a texture of pegmatites, and which represent simultaneous crystallization. While the rock is not one of granitic composition except very locally, yet enough quartz occurs to have produced feldspar-quartz intergrowths, had simultaneous crystallization of these two minerals resulted. On the other hand, intergrowths of the feldspars in the rock is the rule, and this texture is observed both in hand specimens and in thin rock sections. In the syenite pegmatites of Norway, Brögger[a] has shown that perthitic intergrowths of the different feldspars are a characteristic feature.

The nelsonite bodies of irregular, dikelike form described on pages 100-155 of this report are found principally in the syenite of the Roseland district, but occur also in a few places in the outside gneiss, and entirely in the gneiss in the Lovingston district. They are thought to be basic segregations (pages 151-155) somewhat similar in mode of origin to the well-known segregations of titaniferous magnetite in gabbros. They represent the latest differentiations from the magma which gave rise upon cooling to syenite and other igneous rock types in the area.

The genetic relations existing between the syenite, the nelsonites, and some occurrences of gabbro must be regarded as conclusive evidence against a pegmatitic origin for the rock called syenite. Pegmatites ordinarily represent residual differentiates from igneous magmas, but in this area the nelsonites and some of the gabbros were of later solidification than the syenite.

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[a] Brogger, W. C., Syenitpegmatitgange, 1890, p. 158.

DISTRIBUTION.

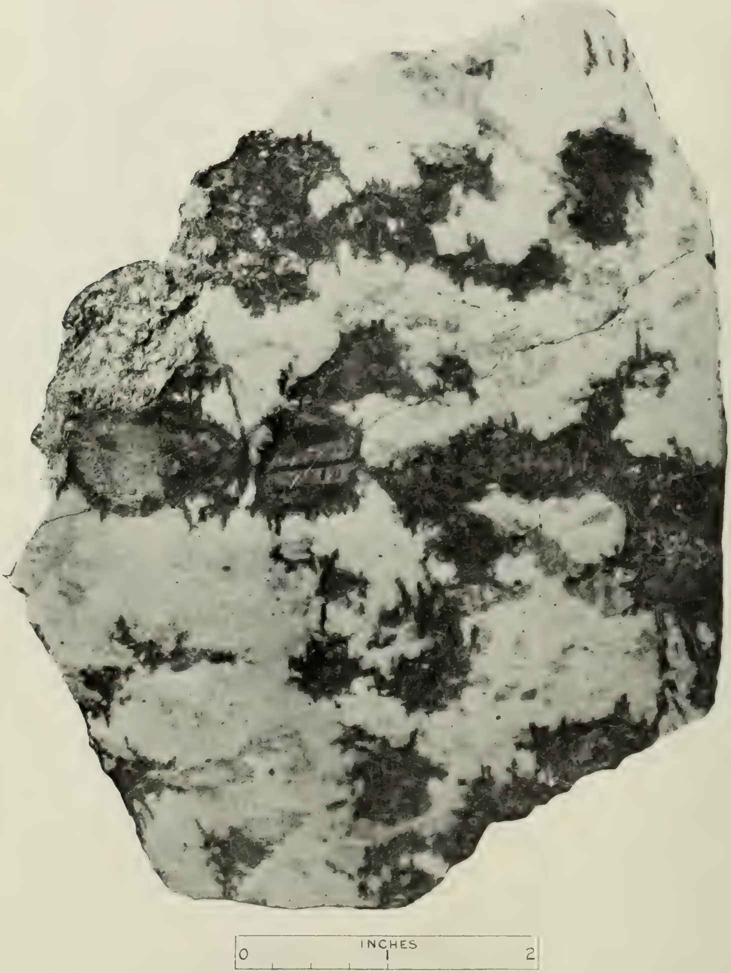
Syenite is the most extensive of the rock types in the immediate rutile district. The large mass lying along the northwest side of the area mapped includes approximately 20 square miles of surface. It occupies a narrow lowland belt that has a general northeast-southwest direction approximately 13 miles in length and not exceeding 2.5 miles in greatest width. (See map, Pl. I.)

MEGASCOPIC CHARACTER.

The rock is usually coarsely crystalline in texture and is frequently gneissic in structure. In places, especially along the southeast border at the American Rutile Company's quarries, the rock displays an abnormal coarseness in texture, in which masses of hornblende, quartz, and feldspar measure several inches across. The rock is composed essentially of feldspar and blue quartz with, in places near the border position, secondary hornblende derived from pyroxene (chiefly hypersthene), rutile, and lesser amounts of ilmenite and apatite. The ratio of these minerals varies greatly in different parts of the rock mass and this gives rise to two varietal forms. Feldspar is the dominant mineral except in portions of the border zone.

Two facies of the rock mass are recognized: (a) Feldspathic, which includes the central and vastly the largest part of the rock mass, and (b) hornblendic, which is developed chiefly as a border zone. The two facies are not separated by a line of sharp demarkation but apparently grade into each other. Feldspar of the same species in the two varietal forms of the rock is a less abundant constituent in the border or hornblendic zone, while hornblende and blue quartz are conspicuous minerals. With but few exceptions rutile, and in smaller quantity ilmenite, are more abundant toward the border portion of the rock mass, especially along the southeast side. This occurrence of the titanium minerals is strikingly shown in the quarries of the American Rutile Company along the east side of Tye River a short distance S. 10° E. of Roseland. Here their occurrence is noted in both facies of the rock with rutile most abundant in the border portion of the feldspathic mass and ilmenite apparently showing greater predilection for the hornblendic zone.

In general, the central portion of the rock mass consists almost exclusively of feldspar, with only scattered grains of quartz, and scarcely any rutile or other visible accessory minerals. The feldspar is usually white, occasionally grayish or pinkish, and frequently shows fine multiple twinning on cleavage surfaces. Not infrequently the larger cleavable



Polished specimen of hornblende syenite from General Electric Company's mine, Nelson County. Dark areas are cores of hypersthene with alteration rims of fibrous amphibole (uralite). Light-colored areas are feldspar containing irregular masses and small grains of blue quartz. (Collected by Frank L. Hess. Photographed by U. S. Geol. Survey.)

HORNBLENDE SYENITE.

individuals show curved and bent lamellæ and granulation from pressure metamorphism.

Deep blue opalescent quartz ranks second in importance as an essential constituent; it is always, though often sparingly, present, and in limited localities may become the dominant mineral. It varies from grains of almost microscopic dimensions to masses many inches across. Merrill[a] states that at one of the openings worked by the American Rutile Company, in 1902, quartz was the dominant mineral, and masses weighing several tons were procured. Like the feldspar the quartz sometimes shows granulation, and in places it is mashed and drawn out into lenses or thin plates, oftentimes imparting more or less of a gneissic structure to the rock.

Hornblende, derived from pyroxene (chiefly hypersthene), is a prominent constituent near the border portions of the rock mass; and it or the original mineral (pyroxene) from which it is derived occurs in variable, usually minute, quantity throughout the area, but in much of the central portion it is virtually absent. It is dark green and frequently fibrous with silky lustre. At the American Rutile Company's quarries it occurs in large cleavable masses, admixed with blue quartz and feldspar, containing disseminated grains of ilmenite and rutile, and not infrequently inclosing variant size grains of blue quartz. The polished surface of a specimen (Pl. VII) taken from the General Electric Company's mine plainly shows rims of hornblende surrounding cores or eyes of the original mineral pyroxene. (See also fig. 15.) Titanium minerals are only sparingly present in the rock at this locality.

Rutile, the fourth mineral in relative abundance, associated with some ilmenite and in places with apatite, varies in amount from practically nothing up to probably 10 per cent in limited areas. It usually occurs in grains of varying size, red to reddish-brown in color, and of adamantine lustre. In distribution the rutile is confined largely to the border portions of the rock mass, being found in largest quantity in the southeast half, but there are a few small areas near the central portion that carry a high percentage of the mineral. In the northwest half of the rock mass rutile occurs in scattered grains that appear to be slightly more numerous near the border portion. The general character and mode of occurrence of the rutile are described in detail on pages 193-196 and 226-229.

Ilmenite, in black grains of varying size, is in general much less abundant than rutile as a constituent of the syenite. It coincides in distribution with that of rutile, but it is more noticeable in the hornblendic portions of the rock mass. Megascopically the mineral presents no unusual features. Apatite is essentially absent as a megascopic constituent of the rock except where rutile or ilmenite occur in large masses, when it is localized in considerable quantity in places.

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[a] Merrill, G. P., Rutile Mining in Virginia, Eng. and Min. Jour., 1902, vol. 78, p. 351.

At several places in the vicinity of the mine formerly worked by the General Electric Company graphite is a prominent constituent, but elsewhere it was not identified in the syenite, though this may be due to the lack of fresh exposures. The sulphides, pyrite and pyrrhotite, were noticed at several points and are probably generally present in small quantity. Sericite is of common occurrence in small quantity as a secondary mineral.

The syenite frequently shows complete or imperfect foliation, especially in the hornblende-rich portions, as in the southeast quarries of the American Rutile Company, and to a less extent where rutile has been concentrated. In places the rock has been crushed to a schist and the rutile mashed into wavy lines of fragments.

MICROSCOPIC CHARACTER.

Microscopic study was made of a very large number of thin sections of both facies of the rock collected from all parts of the area. It was found that these were representative of the two facies of the same rock, showing only such variations as result from the relative abundance of the individual minerals and from structure. The minerals noted in the hand specimens also appear in the thin sections, and in addition a few minor accessories and a longer list of secondary constituents. The thin sections show the following minerals: Feldspar which appears in several species, pyroxene (hypersthene) and more abundantly its alteration product hornblende (uralite), blue quartz, rutile, ilmenite, and minor accessory apatite, zircon (?), pyrite, graphite, and biotite, together with secondary muscovite, epidote, zoisite, kaolin, calcite, leucoxene, garnet, chlorite, and biotite. It is unnecessary to state that these are not all found in the same thin section, and some of them are only occasionally noted. The texture is coarsely granitic, and pressure effects are usually pronounced.

Feldspar is the most abundant constituent, except in portions of the hornblendic facies of the rock, constituting more than 80 per cent of the feldspathic facies of the rock mass. It appears in several species, plagioclase ranging from andesine (dominant) to albite, microcline, and orthoclase. The dominant feldspar is andesine developed in anhedral forms which usually show abundant twin lamellæ after the albite law and to a less extent

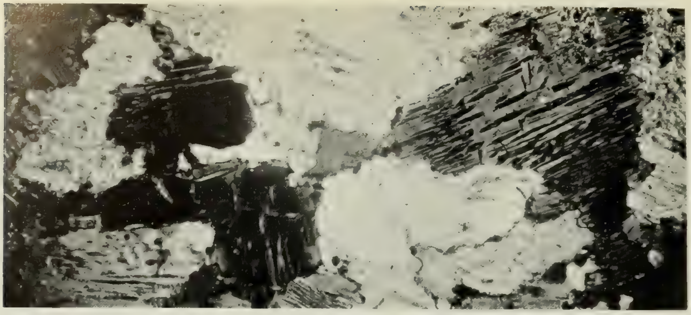


Fig. 1.—Feldspathic facies of syenite from General Electric Company's mine, showing feldspar intergrowths (microperthite). The principal feldspar is andesine with intergrown spindles of orthoclase (microcline). Nicols crossed. Enlarged 30 diameters. Specimen No. 142.

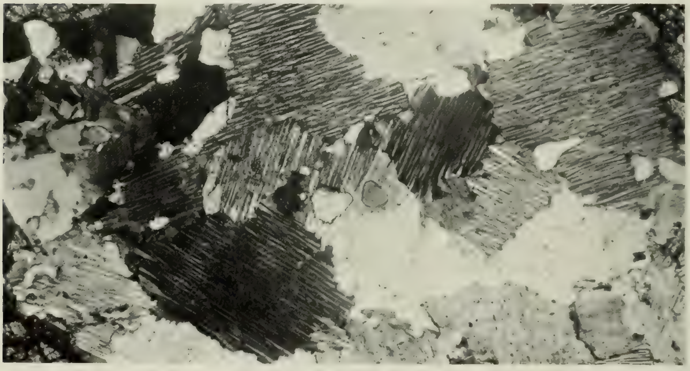
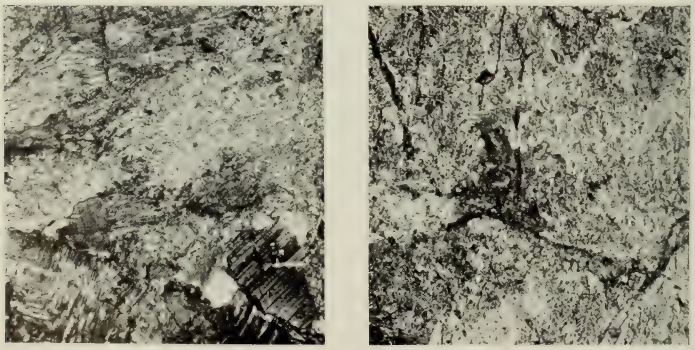


Fig. 2.—Gabbro from W. A. Campbell's farm, Nelson County, showing feldspar intergrowths (microperthite) as in fig. 1. Nicols crossed. Enlarged 30 diameters. Specimen No. 93.



Figs. 3. and 4.—Feldspathic facies of syenite from General Electric Company's mine, and American Rutile Company's quarries, showing a confused aggregate of alteration products from feldspar. Nicols crossed. Enlarged 30 diameters. Specimens Nos. 141-A and 9.

PHOTOMICROGRAPHS OF FRESH AND ALTERED FELDSPAR IN SYENITE AND GABBRO.

after the pericline law. Most of the individuals show spindle-shaped intergrowths of microcline (Pl. VIII, fig. 1) which are often oriented parallel to the twin lamellæ after both laws. The average composition of the plagioclase determined by measurements on the rhombic section, and determination of the index of refraction, corresponds to an andesine of about $Ab_{65}An_{35}$. The intergrown microcline often shows the characteristic grating structure. It appears probable that the more sodic species (albite) present was originally of about the composition of andesine, but in the process of alteration the lime has been removed and deposited as the secondary products zoisite and epidote, leaving a plagioclase rich in soda. Besides their occurrence as spindle-shaped intergrowths with plagioclase, microcline and orthoclase are noted as separate, irregular grains having their usual characters. The feldspar is more or less clouded with minute grains and aggregates of colorless mica (muscovite), epidote, zoisite, and sometimes calcite. In some thin sections alteration is in an advanced stage and the feldspar substance is largely obscured by the alteration products (Pl. VIII, figs. 3 and 4). The feldspar usually contains inclusions of apatite and quartz, less often rutile and graphite, and exhibits distinct evidence of metamorphism in granulation, optical disturbance, curved, bent and broken lamellæ of plagioclase, and recrystallization.

Quartz of pronounced blue color occurs in allotriomorphic areas in greatly varying quantity. It may be entirely absent from some thin sections of the feldspathic facies of the rock though usually present as a subordinate constituent, and always a principal mineral of the hornblendic facies. It is always characterized by great abundance of hairlike inclusions of rutile, and usually shows the result of pressure effects in optical disturbance, granulation, and fractures or cracks. Inclusions of graphite are noted in some thin sections.

Amphibole (uralite), having the composition of actinolite, fibrous, and of blue-green color, is a principal constituent of the border zone of the syenite, but is essentially absent from the feldspathic facies of the rock, forming the central and larger portion of the massif. The usual cleavage of amphibole (uralite) is developed and the fibres generally show a tendency to orientation, but occasionally are bent and broken from pressure effects. It is sometimes studded with minute grains of black oxide of iron and at times contains hairlike inclusions of probable rutile, which are frequently oriented parallel to the fibres, but may also cut across the fibres. Many fragments show parallel extinction, but as a rule an average extinction angle measured on cleavage flakes is about 17°. The indices of refraction measured by the immersion method are: $\propto = 1.620 \pm 0.003$, $\gamma = 1.649 \pm 0.003$, $\gamma - \propto = 0.029$. The average of seven measurements of the birefringence gave $\gamma - \beta = 0.0123$ with values ranging from 0.0115 to 0.0128, $= 0.0126$, $\gamma - \propto = 0.0310$; axial angle measured on pieces cut nearly normal to the acute bisectrix gave an average value of 81°. The mineral is optically negative (—), the optical orientation being that of actinolite. Both the chemical and microscopical studies of the amphibole conclusively prove that it is secondary and has been derived from original pyroxene (hypersthene). (See pages 219-222 for a detailed description and discussion of the uralite.) Idiomorphic compact hornblende has not been observed.

Analyses of uralite and hyersthene of the syenite, Nelson County.
(WM. M. THORNTON, JR., *Analyst.*)

	I	II
SiO_2	52.44	51.31
Al_2O_3	3.51	None
Fe_2O_3	1.46	5.31
FeO	17.11	10.12
MgO	16.73	17.93
CaO	2.98	10.95
Na_2O	0.26	0.22
K_2O	1.24	0.29
H_2O-	0.18	0.04
H_2O+	1.96	1.26
TiO_2	0.94	3.00
MnO	0.52	0.11
P_2O_5	0.05	None
CO_2	None	Trace
S	Trace	None
	99.38	100.54

I. Hypersthene separated from syenite at General Electric Company's mine 1.5 miles northwest of Rose's Mill.
II. Amphibole (uralite) separated from hornblendic facies of syenite at American Rutile Company's quarries near Roseland.

Pyroxene (hypersthene) is the principal original ferromagnesian silicate mineral in the syenite, but in most localities it has been altered by the process of uralitization to hornblende, and it is difficult to obtain fresh pieces. It is developed in large, irregular grains without crystal boundaries, and almost invariably shows alteration rims of fibrous green hornblende. The mineral frequently displays brown-colored inclusions as plates, rods, and grains, which often show definite orientation. Pleochroism is subject

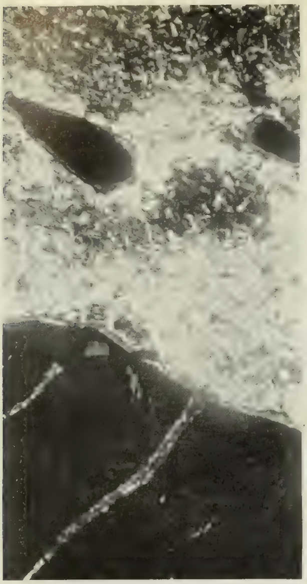


Fig. 1.—Rutile-bearing syenite, American Rutile Company's quarries at Roseland, showing rutile (the two dark grains in upper part of figure and the mass in lower half) rimmed by the alteration product leucoxene. Note the same alteration product filling fracture crossing rutile mass in lower half of figure. Nicols crossed. Enlarged 30 diameters. Specimen No. 42-W. See also Pl. XVI.

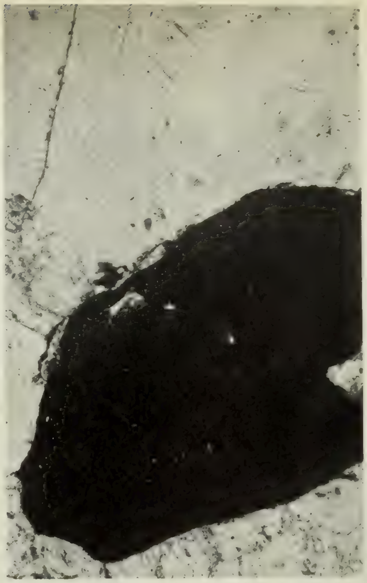


Fig. 2.—Quartz-rutile-bearing syenite, 0.5 mile southwest of Rose Union. Light gray area in upper part of figure is blue quartz containing inclusions of rutile needles; large black area is rutile; remaining light gray areas altered feldspar. Nicols crossed. Enlarged 50 diameters. Specimen No. 110.

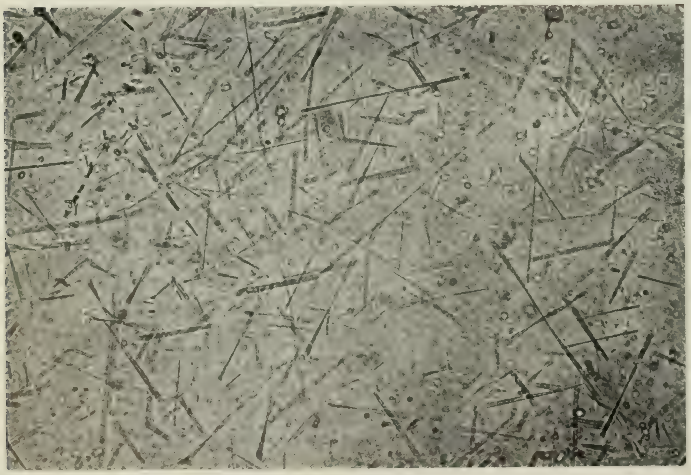


Fig. 3.—Blue quartz in syenite filled with inclusions of rutile needles. General Electric Company's mine. Nicols crossed. Enlarged 375 diameters. Specimen No. 141-B.

PHOTOMICROGRAPHS OF RUTILE ALTERATION AND NEEDLE-LIKE INCLUSIONS OF RUTILE.

to some variation, but is always noticeable: x = pale pink, y = pale yellowish-green, z = pale green. Measured by the immersion method the indices of refraction are: $\alpha = 1.696 \pm 0.003$, $\beta = 1.710 \pm 0.003$, $\gamma = 1.713 \pm 0.003$. Measurements of the birefringence with the Babinet compensator gave an average value of $\gamma - \alpha = 0.018$, $\gamma - \beta = 0.0036$. The average value of the axial angle measured with the Federof stage is $2V = 53°$. (See pages 217-219 for further description.) A chemical analysis of the pyroxene is given above in column I. Brown, pleochroic biotite, partly altered to chlorite, is sparingly developed, and in part at least is probably secondary.

Rutile and ilmenite, sometimes intimately associated, are important constituents of the rock in places, rutile being most abundant in the feldspathic facies, and ilmenite in the hornblendic border zone of the syenite. These are developed in formless grains of variable size and are apt to show partial or complete alteration rims of leucoxene (Pls. IX and XVI). They show their usual characters and are described in detail including chemical analyses on pages 193-196 and 223-229. Rutile as microscopic hairlike inclusions is abundantly developed in the quartz (Pl. IX, figs. 2 and 3). Apatite as separate individuals with rounded and elongated cross-sections and as prismatic inclusions in the other minerals, especially feldspar, is sometimes noted. The remaining accessories, pyrite, graphite, and zircon (?), are very subordinate in amount and do not merit separate descriptions.

Besides uralitic hornblende, the common secondary minerals include muscovite, epidote, zoisite, leucoxene, some kaolin and calcite, and in several thin sections garnet. Except garnet these are usually developed as aggregates of minute scales and granules forming clouded areas in the feldspar.

Pressure effects are invariably shown in the thin sections, chiefly in bent and fractured foliæ of plagioclase, and to some extent the uralite fibres, mashing and granulation, optical disturbance of quartz and feldspar, formation of secondary minerals, especially muscovite, resulting frequently in the development of foliation (Pl. X, figs. 1 and 2).

CHEMICAL COMPOSITION.

The range in chemical composition of the two facies of the syenite (hornblendic and feldspathic) is shown in the analyses of the subjoined table. The analyses representing the two facies of the rock show some differences, due to variation in the proportions of the principal minerals—

feldspar, quartz, and hornblende. Silica varies rather widely for the hornblendic facies, but is quite uniform for the feldspathic facies of the rock. Titania shows great variation in both facies of the rock, ranging from 0.22 per cent in analysis VII to 13.64 per cent in analysis III. Iron oxides (FeO and Fe_2O_3) and magnesia are much higher and the alumina and alkalies (Na_2O and K_2O) are lower for the hornblendic than for the feldspathic facies. Lime, while subject to some variation, is more uniform for the two rock-facies.

Analyses of syenite, Nelson County, Virginia.

(WM. M. THORNTON, JR., *Analyst.*)

	Hornblendic facies			Feldspathic facies				Average A. M. R. Co.
	I	II	III	IV	V[a]	VI	VII	VIII
SiO_2	63.61	56.61	50.97	61.51	60.30	60.03	59.92	59.84
Al_2O_3	15.70	14.89	13.13	23.17	25.70	21.38	24.23	20.59
Fe_2O_3	1.98	1.04	1.44	0.37	None	0.50	0.29	0.55
FeO	3.81	4.32	5.42	0.26	None	0.25	0.24	0.71
MgO	3.58	4.05	4.68	0.26	0.15	0.19	0.23	0.76
CaO	4.50	4.94	3.66	5.96	5.33	4.59	6.47	4.48
Na_2O	3.47	3.19	2.72	4.64	4.28	5.80	5.03	5.23
K_2O	2.12	1.51	2.24	3.94	3.80	2.81	2.93	2.97
H_2O-	0.14	0.08	0.05	0.08		0.16	0.08	0.18
H_2O+	0.97	1.58	1.41	0.32		0.66	0.28	0.75
MnO	0.05	0.01	0.05	Trace		0.01	Trace	0.02
TiO_2	0.40	7.26	13.64	0.29	0.25	3.66	0.22	3.75
P_2O_5	0.15	0.26	0.31	0.10		0.39	0.09	0.35
CO_2	Trace	0.22	0.04	Trace		Trace	Trace	Trace
S	Trace	0.03				Trace	Trace	
	100.48	99.94	99.76	100.43	99.81	100.90	100.01	99.78
Specific gravity				2.705			2.68	2.744

[a] Professor F. P. Dunnington, analyst.

I. Hornblende facies of syenite, 100-foot level, General Electric Co.'s mine, 1.5 miles northwest of Rose's Mill.
II. Horneblende facies of syenite, American Rutile Co.'s quarries, Roseland.
III. Hornblende facies of syenite, American Rutile Co.'s quarries, Roseland.
IV. Feldspathic (gray) facies of syenite, 100-foot level, General Electric Co.'s mine, 1.5 miles northwest of Rose's Mill.
V. Feldspathic facies of syenite, American Rutile Co.'s quarries, Roseland.
VI. Feldspathic facies of syenite, American Rutile Co.'s quarries, Roseland.
VII. Feldspathic (pinkish) facies of syenite, 100-foot level, General Electric Co.'s mine, 1.5 miles northwest of Rose's Mill.
VIII. Average bulk sample of syenite, including hornblende and feldspar facies, American Rutile Co.'s quarries, Roseland.

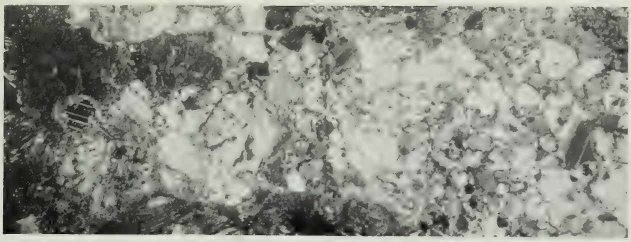


Fig. 1.—Feldspathic facies of syenite, General Electric Company's mine, showing granulation of feldspars from dynamic metamorphism. Nicols crossed. Enlarged 30 diameters. Specimen No. 148.

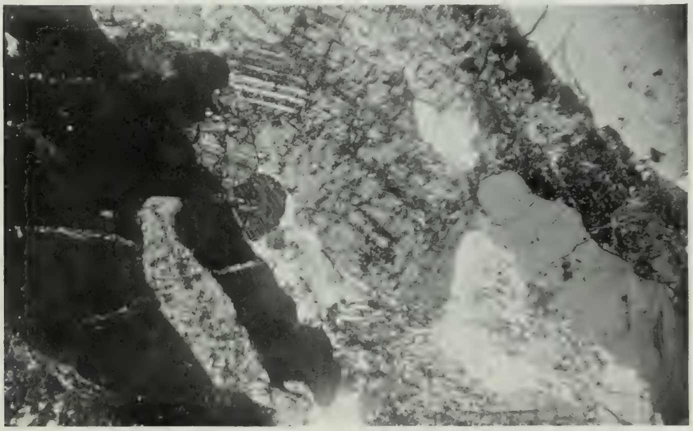


Fig. 2.—Feldspathic facies of syenite near entrance to Major Boyd's farm, 0.5 mile southeast of Bryant, showing banding from dynamic metamorphism. Nicols crossed. Enlarged 30 diameters. Specimen No. 77.

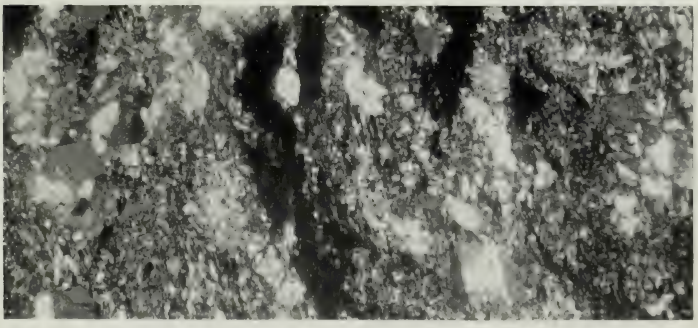


Fig. 3.—Uralitized gabbro-gneiss derived from gabbro by metamorphism. American Rutile Company's property. Nicols crossed. Enlarged 30 diameters. Specimen No. 14.

PHOTOMICROGRAPHS OF SYENITE AND GABBRO-GNEISS.

Attention is directed in the analyses to the high percentages of lime and soda; in general the two vary directly with each other, indicating the source of lime to be chiefly from feldspar of the soda-lime series, the composition of which is discussed below. In every case soda exceeds potash, ranging molecularly from two to four times as great, showing that potash feldspar in the rocks is quite subordinate in amount to the soda-lime species, a fact confirmed by microscopic study.

Computing the mineral composition of the feldspars from the percentages of potash, soda, and lime[a] given in the table of analyses above, by allotting the potash to orthoclase, and the soda and lime to albite and anorthite of the plagioclase series, the analyses correspond to the following feldspar composition:

Feldspar composition of syenite, Nelson County, Virginia.

(Numbers correspond to table of analyses above.)

	I	II	III	IV	V	VI	VII	VIII
Orthoclase	12.23	8.90	12.79	23.35	22.24	16.68	17.24	15.57
Albite	29.34	27.25	23.06	39.30	36.16	49.25	42.44	44.02
Anorthite	21.13	21.68	16.96	28.63	26.41	21.68	31.14	20.57
Total plagioclase	50.47	48.93	40.02	67.93	62.57	70.93	73.58	64.59
Total feldspar	62.70	57.83	52.81	91.28	84.81	87.61	90.82	80.16
Ab_nAn_m ratio	1.4:1	1.3:1	1.4:1	1.4:1	1.4:1	2.3:1	1.4:1	2:1
Or.-plag. ratio	1:4	1:5	1:3	1:3	1:3	1:4	1:4	1:4

Designating the albite molecule ($NaAlSi_3O_8$) by *Ab*, and the anorthite molecule ($CaAl_2Si_2O_8$) by *An*, the soda-lime species correspond closely to the following molecular ratios:

I. Ab_7An_5 = Andesine.
II. Ab_7An_5 = Andesine.
III. Ab_7An_5 = Andesine.
IV. Ab_7An_5 = Andesine.
V. Ab_7An_5 = Andesine.
VI. $Ab_{12}An_5$ = Andesine.
VII. Ab_7An_5 = Andesine.
VIII. Ab_2An_1 = Andesine.

As calculated from the analyses, it will be observed that in general the composition of the dominant feldspar present in the two rock-facies of the syenite is a calcic-soda species, corresponding to andesine. This is confirmed by microscopic study of thin sections of the rocks. These calculations show the proportions of orthoclase (microcline) to plagioclase to range from 1:3 to 1:5.

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[a] Sufficient lime was allotted in each case to the percentage of P_2O_5 found on analysis to form the mineral apatite.

A further noteworthy feature developed in the calculations (readily apparent from study both of hand specimens and thin sections) is the richness of the rocks in feldspar, especially the feldspathic facies. In this respect this facies of the rock is closely akin to the group of anorthosites, but the difference in the two types is at once apparent in the dissimilarity of the feldspar species which characterize each. The total feldspar varies, however, in the two facies of the syenite within wide limits, as may be observed from the table, being lowest of course in the hornblende facies of the rock, in which the range of total feldspar is about that of the so-called granites (quartz monzonites chiefly).

CLASSIFICATION.

The norms corresponding to, and computed from, the analyses on page 76 are given in tabular form below.

Norms of syenite corresponding to analyses on page 76.

Minerals	Hornblende facies			Feldspar facies				Average A. M. R. Co.
	I	II	III	IV	V	VI	VII	VIII
Quartz	18.80	16.26	12.36	6.66	19.42	5.70	5.82	9.48
Orthoclase	12.23	8.90	12.79	23.35	22.24	16.68	17.24	15.57
Albite	29.34	27.25	23.06	39.30	36.16	49.25	42.44	44.02
Anorthite	21.13	21.68	16.96	28.63	26.41	21.68	31.14	20.57
Corundum	......	......	......	0.71	4.90	0.82	1.33	1.63
Hypersthene	13.52	10.10	11.70	0.60	0.40	0.50	0.60	1.90
Ilmenite	0.76	9.11	11.40	0.61	......	0.61	0.46	1.52
Hematite	......	0.96	1.44	0.48	......	0.48	0.32	0.48
Magnetite	3.02	......	......	......	......	......	......	......
Titanite	......	1.37	0.39	......	......	......	......	......
Rutile	......	1.94	7.44	......	0.32	3.36	......	2.96
Apatite	0.34	0.67	0.67	0.14	......	1.01	0.34	0.67
	99.14	98.24	98.21	100.48	99.85	100.09	99.69	98.80
Water	1.11	1.66	1.46	0.40	......	0.82	0.36	0.93
Not used	0.05	0.26	0.09	......	......	......	......	0.02
	100.30	100.16	99.76	100.88	99.85	100.91	100.05	99.75

The positions in the "Quantitative System" of the eight rocks corresponding to the norms tabulated above may be expressed as follows:

Summary of Quantitative Classification.

No.	Symbol	Name	Name proposed
I.	′II. 4. 3. 4.	Tonalose.	
II.	II. 4. 3. 4.	Tonalose.	
III.	II′. 4. 3. ′4.	Tonalose.	
IV.	I. 5. 3. 4.	No name—analyses known.	Piedmontose.
V.	I. ′5. 3. ′4.	No name—analyses known.	Piedmontose.
VI.	I. 5. ′3. 4.	No name—analyses known.	Piedmontose.
VII.	I. ′5. 3. 4.	No name—analyses known.	Piedmontose.
VIII.	I′. ′5. 2. 4.	Laurvikose.	

Based on mineral composition the hornblende facies of the rock mass corresponds in the older terminology to granodiorite. As discussed elsewhere in this report hornblende of the rock is shown to be secondary derived from pyroxene (hypersthene), and the original rock probably corresponded more closely to gabbro, although the texture is vastly coarser than that of normal diorite and gabbro. This textural difference is accounted for on the basis that the minerals crystallized under conditions different from those in a normal rock, that is from magma supercharged with vapors.

Each of the three analyses (I, II, and III) of the hornblende facies of the rock mass corresponds, in the quantitative classification, as indicated in the summary above, to the subrang name *tonalose.* The norms computed from the three analyses agree, therefore, in placing this rock into class II (dosalane), order 4 (quardofelic), rang 3 (alkalicalcic), and subrang 4 (dosodic), and is designated *tonalose.* The principal types of plutonic rocks included in Washington's[a] tables under *tonalose* are diorites and granodiorites.

The feldspathic facies of the rock mass, which composes vastly the largest part of the massif in the field, and represented by analyses (IV, V, VI, and VII), probably corresponds more closely in the older classification to syenite, notwithstanding the fact that the dominant feldspar is a soda-lime species. Although syenites are considered to contain orthoclase as the dominant feldspar, the numerous analyses indicate that only a few are dopotassic rocks, the great majority being either sodipotassic or dosodic. Both the chemical analyses and microscopic study of thin sections of the Nelson County rock indicate too high a percentage of potash feldspar and too sodic plagioclase (andesine),[b] which latter is the dominant feldspar present, to group the rock as anorthosite, most of the analyses of which correspond to docalcic, persodic rocks (labradorose), and a few to percalcic (canadase). Neither could the rock be classed as monzonite under Brögger's[c] definition, the type of which in the "Quantitative System" is *monzonose,* and is sodipotassic. The analyses show the rock to be characterized by dominant soda over potash (dosodic), and the proportion of alkalies and lime nearly equal (alkalicalcic). The position of the rock then in the older classification would be intermediate between the alkali and lime-soda feldspar groups (monzonites) and the lime-soda feldspar group (anorthosites), corresponding to dosodic syenite.

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[a] Washington, H. S., Professional Paper No. 14, U. S. Geol. Survey, 1903, pp. 235-241.

[b] The name anorthosite is now applied to grained rocks composed almost entirely of lime-soda feldspar, with negligible amounts of other minerals. The commonest variety of anorthosite, however, is composed of the lime-soda feldspar, labradorite.

[c] Brögger, W. C., Die Eruptivgesteine des Kristianiagebietes, 1895, vol. ii, p. 21.

As indicated in the summary above, the four norms (IV, V, VI, and VII) computed from the analyses are in agreement (being expressed by the same symbol) and the rock falls into an unoccupied or new position in the "Quantitative System." Although analyses of rocks are reported known that would correspond to this position, no name has yet been proposed for this representative. Since the Nelson County, Virginia, feldspar-rich rock (consisting normally of little else than feldspar) covers an extensive area, and the several accurate and complete analyses were made on reasonably fresh material collected from different localities within the area, *piedmontose* is proposed by the writers as an appropriate subrang name for this new representative.

The exact position of this new type in the quantitative classification would be expressed as follows:

Class I. Persalane.
Order 5. Canadare.
Rang 3. *Piedmontase.*
Subrang 4. *Piedmontose.*

The rock is the first recorded representative of the rang and subrang, and *piedmontase* (rang) and *piedmontose* (subrang) are suggested as appropriate names.

The norm calculated from analysis VIII, made on a carefully collected sample from the American Rutile Company's quarries at Roseland, and representing a bulk (composite) sample of the two facies of the rock mass, places it into class I (persalane), order 5 (perfelic or canadare), rang 2 (domalkalic or pulaskase), and subrang 4 (dosodic or *laurvikose*), and is designated *laurvikose.* It is closely similar to *piedmontose,* differing only in the rang position, which in this case expresses the proportions of alkalies and lime in the normative feldspars.

It is worthy of note that the eight analyses representing the two facies (hornblendic and feldspathic) of the rock are alike in showing dominant soda over potash, and are grouped quantitatively as dosodic.

VARIATIONS IN THE SYENITE.

The most extensive exposures of the freshest syenite were found in the mine of the General Electric Company and in the open cuts (quarries) of the American Rutile Company. Complete description of the syenite at these two localities is given on pages 163 and 179. The following descriptions of the syenite from numerous widely separated localities will give a general idea of the variations in the rock mass.

On the Cox farm, 1.5 miles northwest of Rose Union, there is a small area in which the percentage of rutile is extremely high, amounting perhaps to 10 per cent. The surface is almost covered in places with gravel consisting of pebbles of rutile and quartz which have been weathered out from the syenite and become concentrated on the hill slope. A prospect pit sunk through the residual rock decay reached the fresh syenite at a depth of little over 6 feet. The syenite is entirely free from hornblende or pyroxene consisting of feldspar, rutile, quartz, and a few scattered grains of ilmenite. The feldspar is white, partly perthitic in texture, and in places shows fine multiple twinning. Large warped cleavage planes afford evidence of dynamic metamorphism. Rutile occurs in irregular angular grains having a maximum diameter of 1 cm., arranged in irregular broken lines running in various directions. Blue quartz is present in irregular masses ranging up to 3 cm. in diameter. A thin section of the rock (Spec. 101) examined microscopically exhibits no unusual characters from the normal rutile-bearing feldspathic facies of the syenite described on pages 72-75. There are several other localities in this immediate vicinity where rutile occurs in considerable quantities.

Plate XXXVI, fig. 2, facing page 252, is a photograph of a specimen of blue quartz and rutile from the Cox farm.

Large pieces of loose rutile are found on the surface 1.25 miles west of Rose Union intimately associated with large weathered boulders of syenite. When broken open the syenite boulders (Spec. 105) are found to be honeycombed with large angular cavities ranging up to 3 cubic inches in size. The cavities contain a white porous residue consisting mostly of earthy apatite, and it is probable that the cavities are due to removal of this mineral by solution. They are frequently separated by narrow partitions about an eighth of an inch in thickness composed of feldspar, blue quartz, and rutile. No minerals other than the ones mentioned could be identified in the rock.

On the south side of Allen Creek, about half a mile southwest of Rose Union, a large exposure of syenite occurs composed of white feldspar with much graphite and pyrite. A few scattered grains of blue quartz could be distinguished but no other minerals were identified. Passing up the creek from this point graphite in small flakes may be found in most of the rock exposures, and at a distance of about a quarter of a mile some large pieces of rock weighing more than twenty-five pounds were procured from the bed of the creek that appear to be composed entirely of graphite and pyrite. The pyrite is rapidly oxidized on exposure to the air. Passing down the creek graphite was also found at several places. About three-quarters of a mile northwest of Rose's Mill an exposure of gneissic syenite in which quartz is dominant over feldspar shows numerous small flakes of graphite and a few grains of rutile and ilmenite.

Near this exposure is another in which graphite is absent. The syenite is gneissic in structure and composed for the most part of feldspar, bluish gray quartz, hornblende, and numerous scattered grains of rutile. A thin section of the rock (Spec. 110) shows the usual primary and secondary minerals which characterize the feldspathic facies of the syenite. Evidence of dynamic metamorphism is manifested in fractures, wavy extinction, and granulation of the quartz and feldspar.

In the bed of a small branch, 1.5 miles southeast of Lowesville, syenite is exposed which consists largely of blue quartz with smaller amounts of kaolinized feldspar and numerous small grains of rutile.

Fresh syenite of medium-grained texture and gneissic structure was exposed in blasting for the foundation of a building on Mr. J. Hill's farm, half a mile northeast of Rose Union. The rock (Spec. 132) is composed chiefly of feldspar, together with gray quartz in fine lines or stringers, pyroxene, and a few grains of rutile and ilmenite.

On Col. J. T. Hubard's farm, about 1.25 miles northeast of Rose Union, much rutile-bearing float is found scattered over a small area. The loose rock fragments are similar in appearance to the syenite described on page 83 and reproduced in Pl. XXXIII. The rock (Spec. 138) is composed of large feldspar masses 10 cm. and more in diameter surrounded and separated by a mixture of rutile, apatite, blue quartz, and feldspar. A little secondary muscovite is also noted.

In a field three-quarters of a mile north of Roseland is an isolated outcrop of schist derived from the syenite by local crushing. The rock is much weathered. Small grains of rutile may be identified and lenses of blue quartz occur in the outcrop, but are not visible in the hand specimen which seems to be practically free from quartz. The schistose structure of the rock (Spec. 20) is strongly developed in the thin section under the microscope. The principal minerals are andesine and orthoclase feldspar, nearly colorless to greenish-brown fibrous hornblende, some quartz containing rutile needles, and several small grains of rutile partly altered to leucoxene. The feldspar is granulated and fractured from pressure effects and considerably altered to epidote, zoisite, and muscovite. In many cases the hornblende fibres are bent and broken from pressure metamorphism.

About three-quarters of a mile northwest of Roseland, near Tye River, is an exposure of pronounced schistose syenite of the hornblendic facies, in which feldspar, blue quartz, and hornblende are the megascopic constituents. This outcrop is within 500 yards of the syenite-biotite gneiss contact where crossed by Tye River. For some distance south and east of this point the syenite is of the feldspathic facies composed almost entirely of feldspar with very little blue quartz and no hornblende, so that the rock weathers to a white clay; but, passing northeastward the character of the rock soon changes as the contact is approached. The section across the contact at this point is described on page 84. Schistose structure is evident in the thin section of the rock (Spec. 22) which exhibits the usual mineral composition. The principal alteration products are epidote, zoisite, and colorless mica. Granulation and undulous extinction of the light-colored minerals are noted.

On the north side of the county road, about a quarter of a mile northeast of Bryant, are several reeflike exposures of schistose syenite (Pl. XXIV, fig. 2). The rock is a medium coarse-grained mixture of feldspar, blue quartz, hornblende, rutile, and biotite. The quartz is drawn out into long, broken stringers oriented along a N. 50°-60° W. direction. Rutile occurs in disseminated grains. This is the only locality where biotite was observed as a noticeable megascopic constituent of the syenite. Some of the exposures exhibit the same pitted weathering effect of the rock surface as observed on the east side of Tye River above Roseland (Pl. V). When studied in thin section under the microscope the rock (Spec. 57) conforms entirely in mineral composition to the hornblende-bearing syenite.

Specimen 222, taken from an outcrop near the entrance to Major Boyd's farm half a mile southeast of Bryant, is a foliated rock composed of light bands of feldspar with a little quartz, which alternate with dark bands containing deep blue quartz, ilmenite, and a little biotite. Except for the presence of brown biotite, a thin section of the rock shows the usual composition of the syenite. The schistose structure is plainly marked in the section accompanied by the development of much secondary colorless mica, and granulation of the quartz and feldspar. (Pl. X, fig. 2.)

On the slope of the mountain about a mile east of Bryant exposures of gneissic syenite (Spec. 226) occur composed of feldspar, some of which exhibits multiple twinning, light pink garnets about 2 mm. in diameter, and small grains of rutile.

About 700 yards southwest of the American Rutile Company's quarries, in the bluff bordering the lowlands on the west side of Tye River, there is an exposure of the feldspathic facies of syenite carrying much rutile.

The photograph of the polished specimen reproduced in Pl. XXXIII was obtained from a small opening made in this outcrop. The syenite consists of an aggregate of large, white feldspar individuals averaging 4 to 5 cm. in diameter through which are distributed irregular bands, lenses, and smaller areas ranging up to 2 cm. in width, composed of brownish-red rutile, grayish-white to glassy apatite, blue quartz, and smaller grains of feldspar. The large feldspars are partly perthitic in texture and show good cleavage development, the surfaces of which are slightly bent in some cases. There are inclusions of the other minerals principally rutile in the feldspar, and these increase in number near the borders. The blue quartz is for the most part intimately associated with the rutile, but the apatite is more often separately segregated. The rutile is in irregular grains ranging up to 1 cm. and over in diameter. The apatite occurs in grayish-white to transparent granular crystals. A few small, scattered flakes of muscovite may be distinguished, but the rock is practically free from hornblende or other ferromagnesian minerals. The rock plainly shows the effects of intense dynamic metamorphism.

CONTACTS.

Because of the extensive residual rock decay which conceals the fresh rock, contacts between the syenite and outside biotite gneiss are exposed in but few places. The contact is often indicated by a change in color of the soil, as the syenite where free from hornblende weathers to a white clay and the gneiss usually to a red clay or gray sandy soil. Close to the contact the red clay is often much deeper in color, indicating a higher percentage of iron oxide. The presence of small pebbles and grains of rutile concentrated on the surface also helps in tracing the syenite.

Gneiss-syenite contact on the southeast side.—The only place in the region where a sharp contact was found between the syenite and biotite gneiss was in exposures of moderately fresh rock on the southeast side of the syenite area shown in the photograph on Pl. XI, fig. 1. The photograph was taken in the bed of Allen Creek half a mile north of Rose's Mill and about 75 yards southwest of the county road. The line of contact between the two formations runs diagonally across the photograph and directly under the hammer shown near the center.

Several deep gullies have been cut in the residual rock decay near the contact between the syenite and biotite gneiss 1.25 miles west of Rose's Mill. A photograph taken in one of these gullies is reproduced in Pl. IV, fig. 2. It shows the irregularity of the rocks near the contact and inclusions

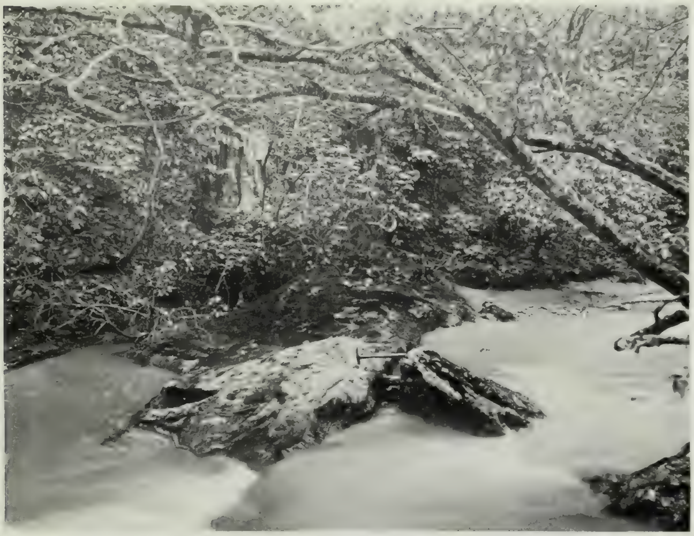

Fig. 1.—Contact between syenite and biotite-quartz monzonite-gneiss exposed in bed of Allen Creek, 0.5 mile north of Rose's Mill. Hammer indicates position of contact.

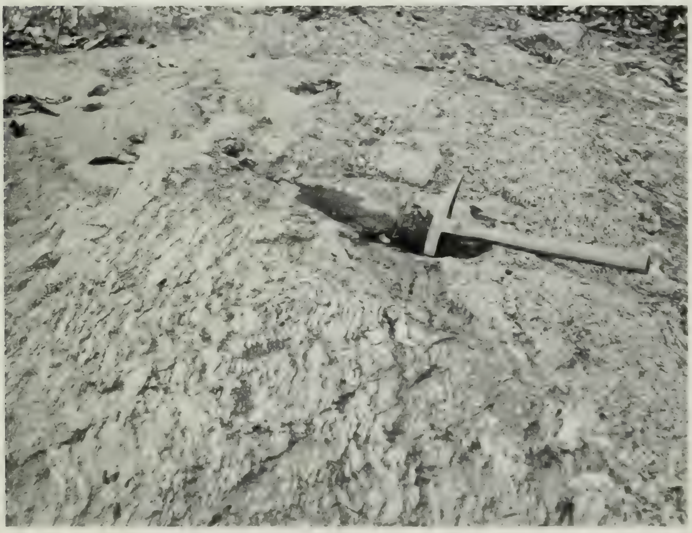

Fig. 2.—Banded syenite-gneiss near contact between syenite and biotite-quartz monzonite-gneiss. East bank of Tye River, 1 mile northwest of Roseland.

SYENITE-GNEISS CONTACT AND BANDED GNEISS.

of large, angular masses of light-colored material in the darker rock. Both rocks are completely decayed by the action of atmospheric agencies (weathering).

Along the east side of Tye River, extending downstream in a southeast direction from the American Rutile Company's quarries, a body of uralitized gabbro more or less schistose in structure lies between the syenite and biotite gneiss. On the west side the gabbro apparently grades into the hornblendic facies of the syenite, while on the east side the exact nature of the contact between the gabbro and gneiss is indeterminate because of lack of outcrops and thick mantle of residual rock decay. Probably similar relations obtain farther northeast along the same boundary about 1.5 miles southeast of Bryant, where gabbro masses are again developed and in similar position with reference to the syenite and biotite gneiss. Here, as along the border zone in general, lack of exposures and depth of residual rock decay render accurate observation and interpretation of the exact nature of the contacts between the individual rock masses uncertain.

Three-quarters of a mile southeast of Roseland and within 200 or 300 yards of the syenite contact is a large exposure of biotite gneiss in which the principal minerals—feldspar, quartz, and biotite—are distinguishable megascopically. Microscopically the rock (Spec. 36) is identical in structure and mineral composition with the normal biotite gneiss. A sprinkling of both apatite and rutile is developed in thin section, and the usual evidence of pressure metamorphism is pronounced.

The gneiss-syenite contact is probably located half a mile east of Roseland and just north of Mr. Wilson's residence, as the change in color of soil from light gray to dark red is marked. A specimen (35) taken from a piece of float at this point indicates both megascopically and microscopically a rock of essentially the same composition as the outside biotite gneiss. An outcrop on the side of a small stream three-quarters of a mile northeast of Roseland is composed of gneiss (Spec. 33) of essentially the same general character as specimen 35, except that some blue-green fibrous hornblende is present in addition to biotite. The same rock in a more advanced stage of weathering is exposed in the creek bed for a distance of several hundred yards, and again a quarter of a mile farther east as indicated by a piece of float (Spec. 32) which from microscopic study is biotite gneiss of the usual character.

On the east side of the road 100 yards north of Rose's Mill and 600 yards from the syenite-gneiss contact on the southeast side is a large exposure of the typical biotite gneiss cut by several dikes of diabase (page 160). The rock (Spec. 129) is a dark gray foliated gneiss containing feldspar eyes ("augen") about 0.75 cm. in diameter, biotite, and some white quartz. Microscopically the rock is identical with that occurring on the Arrington-Roseland road one mile north of Colleen, and yielding the chemical analysis shown in column I, page 63.

Gneiss-syenite contact on the northwest side.—In some places near the contact the syenite is interleaved with bands of a fine-grained gabbroic rock, so that it presents the appearance of a banded and often contorted gneiss. The bluffs along the east side of Tye River about 2 miles northwest of Roseland furnish the best section across the contact that is found at any locality on the northwest side of the syenite area, and for that reason it is described in some detail below.

On the river bank about 300 yards from the contact there is exposed a large bare surface of gneissic syenite polished smooth by river erosion. The rock consists of alternating bands of light- and dark-colored minerals that have become greatly contorted through intense folding and minor faulting (see Pl. XI, fig. 2). The dark bands are due to the presence of hornblende and the light-colored ones are composed of feldspar with occasional small lenses of blue quartz. In other portions of the outcrop the dark bands are absent and there is sufficient blue quartz present to form stringers. Some of the bands have the appearance and composition of gabbro. The general strike of the schistosity is S. 55° W., and it appears to dip toward the northwest at an angle of about 70°.

The rock shows two principal directions of jointing; the earliest fractures have a strike of about N. 70° W., but are not very strongly developed, while the later joints are well defined, having a strike of N. 23° W., and in places show slight faulting with displacement of the previous fractures. The faulting was uniformly toward the left, the greatest individual displacement observed being about 8 inches. The folding shown by the contorted bands of the rock is due to displacement without fracture in the same direction. In some parts of the exposure very little contortion is observed. Because of difference in mineral composition, the alternating bands of the rock give rise in places to remarkable examples of differential decay. A few yards back from the river and above the reach of high water there is an outcrop showing the deep-pitted rock surface due to weathering described on page 47 and shown in Pl. V.

Passing upstream from this point and approaching the contact with the biotite gneiss, the rock exposures vary constantly in appearance and composition, showing in one place gabbro and in another typical syenite, but retaining as a whole the banded or interleaved structure. Detailed lithologic descriptions follow:

Specimen 23 was taken from the river bluff about one mile northwest of Roseland and within 100-200 yards of the contact. It is a light brown gneiss of even-granular texture, composed of white plagioclase feldspar, showing fine multiple twinning, garnets in irregular brown grains about 2 mm. in diameter, hornblende, and numerous flakes of graphite ranging up to 3 mm. in length. Microscopically a thin section shows a medium granular rock of granitic composition. The principal minerals are plagioclase and potash feldspars partly intergrown, quartz containing inclusions of rutile needles, large irregular areas of garnet considerably fractured, irregular areas of graphite, apatite as inclusions in the other minerals, chiefly feldspar and quartz, much secondary colorless mica, epidote, zoisite, and leucoxene. A single large grain of rutile was identified.

About 75 yards farther north another specimen (24) was taken of a dark brown gneiss whose minerals are arranged in distinct bands. It contains white plagioclase feldspar which with the aid of a lens exhibits fine multiple twinning, hornblende, a little blue quartz, and a few scattered grains of ilmenite. Graphite in small flakes is also very sparingly present and possibly some light-colored garnet, but this is uncertain. The contact between the rutile-bearing rocks and the biotite gneiss passes very close to this point, but is concealed by the residual rock decay and can not be definitely located. A thin section of the rock (Spec. 24) shows it to be a uralitized gabbro of the same composition as that occurring on the southeast side of the syenite area. The minerals are plagioclase (andesine) intergrown with orthoclase, greenish-brown hornblende derived from pyroxene, much brown biotite, magnetite or ilmenite partly altered to leucoxene, a little apatite, and a single grain of rutile. The feldspars are altered and the thin section shows pronounced evidence of pressure metamorphism.

About a quarter of a mile farther northwest at the head of an old mill race is an outcrop of syenitic rock that probably represents an apophysis, as it is located at some distance from the main syenite mass and wholly within the biotite gneiss. The rock (Spec. 25) is composed of feldspar and grains of blue quartz that show a suggestion of graphic texture. It has been rendered schistose by intense crushing and shearing accompanied by the development of secondary muscovite along the planes of schistosity. A vein of white quartz penetrates along one side of the outcrop.

A thin section cut from a hand specimen of the rock, shows the chief feldspar to be microcline intergrown with some plagioclase. There occur also individual crystals of plagioclase always more or less altered to white mica and zoisite with some calcite and epidote. Extinction angles on the rhombic and other sections show the plagioclase to be albite, none of which showed a higher anorthite content than $Ab_{92}An_8$. It seems probable that the plagioclase was originally of about the same composition as that of the other sections, and in the process of alteration the lime has been removed and deposited as zoisite, leaving a soda-rich feldspar. Oriented intergrowths of quartz are common in the plagioclase crystals. In addition to the plagioclase intergrowths, the microcline contains some quartz which may or may not be oriented, and included apatite.

On the south side of the river about a mile south of Massie's Mill and fifty yards above Cow Hollow Ford there is an outcrop of gneissic rock which is similar to the one last described. The rock consists of large oval-shaped crystals of feldspar, irregular broken stringers of blue quartz, and secondary muscovite and biotite. (See fig. 4.) The mica has the appearance of being wrapped around the feldspar and quartz individuals, and upon weathering the latter stand out in strong relief. Microscopically a thin section of the rock (Spec. 26) shows, except for the presence of biotite, a similar composition to that described above (Spec. 25). Colorless mica, epidote, and kaolin are the common secondary minerals derived from alteration of the feldspar.

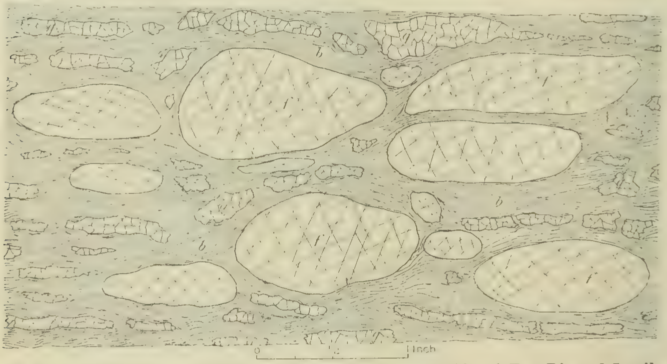

Fig. 4.—Sketch of porphyritic gneiss exposed on south side of Tye River 1.5 miles north of Claypool. (*b*) Biotite chiefly, (*f*) feldspar, (*q*) blue quartz.

Specimen 28, taken from an outcrop of the biotite gneiss exposed in the road cut about half a mile south of Cow Hollow Ford, is a gray, coarsely crystalline rock in which feldspar, biotite, muscovite, and a few grains of light blue quartz are identified megascopically. Under the microscope the rock shows identical composition in both principal and accessory minerals with the outside normal biotite gneiss of the region described on pages 59-66. The thin section shows considerable alteration of the principal minerals, especially the feldspars. Granulation of the feldspar and quartz resulting in the development of fine-grained mosaics of the two minerals from pressure metamorphism is very pronounced.

About half a mile northeast of Jonesboro, within the biotite gneiss area, but not far from its contact with the syenite, occurs an exposure of fine-grained, dark green amphibolite schist, with numerous loose fragments of the rock scattered over the surface. Schistose structure is apparent in the thin section (Spec. 46) which is composed chiefly of nearly colorless to blue-green fibrous hornblende. Zoisite and leucoxene are developed as minor secondary minerals.

Specimen 62, obtained from an outcrop on the side of the mountain three-quarters of a mile northwest of Bryant, is a fine-grained gneiss whose megascopic constituents are feldspar, quartz, biotite; and ilmenite. When studied in thin section under the microscope the rock is shown to be of the same composition as the normal biotite gneiss of the region described on pages 59-66. Specimen 65, taken a quarter of a mile north of Bryant and close to the biotite gneiss-syenite contact, is essentially identical in texture and composition with specimen 62.

Specimens 67, 68, 69, and 70, collected from outcrops 20 to 30 yards apart, close to the biotite gneiss-syenite contact about three-quarters of a mile northeast of Bryant, are much altered from weathering, but show the textural variations often observed in the biotite gneiss, especially near the northwest border of the syenite. They are composed of essentially the same minerals, feldspar, quartz, and biotite, are schistose in structure, but vary from fine- to medium coarse-grained in texture. High up on the side of the mountain, at a distance of one mile from the syenite contact with the biotite gneiss, are bold exposures of dark gray gneiss showing lenticular eyes (phenocrysts) of feldspar, and smaller amounts of biotite and quartz. Microscopically the rock is identical in composition with the normal biotite gneiss of the area.

About 1.5 miles northeast of Bryant the syenite apparently fingers out into the surrounding biotite gneiss, and pegmatite or granite dikes are developed for some distance beyond the main syenite mass. Fairly good exposures of these are shown in the bluff along the east bank of Hat Creek 3.5 miles northeast of Bryant. The rock at this point is badly weathered but a fresh specimen was obtained from a loose piece a short distance below, which shows a medium coarse-grained rock composed of feldspar and bluish-gray quartz with a little chlorite and a few grains of ilmenite. The feldspar shows good cleavage development and frequently contains rounded inclusions of quartz measuring 0.5 mm. in diameter. Microscopically the rock (Spec. 223) corresponds to granite in composition. The principal minerals are feldspar (microcline, plagioclase near oligoclase, and some orthoclase) greatly altered to an aggregate of colorless mica and epidote, quartz containing inclusions of rutile needles and dustlike particles as well as those of liquid or gas, brown pleochroic biotite, and ilmenite altered peripherally to leucoxene.

The rock observed near the north end of the syenite area, just before it fingers out into the surrounding biotite gneiss, is very schistose in structure, the minerals being mashed out into thin parallel lines. Feldspar, blue quartz, and hornblende are the principal minerals, but they vary much in their relative proportion. Ilmenite is present in places.

Mars Mountain.—The peak locally called Mars Mountain, located one mile southwest of Bryant, is composed largely of biotite gneiss of the same general character as that described on pages 59-66. It is almost if not entirely surrounded by the syenite, but appears to be connected with the outside biotite gneiss on the west side. This connection could not be definitely established because of the complete burial of the rocks at this point under the alluvial material in Hat Creek valley. Because of its greater resistance to weathering and erosion, the gneiss forms the mountains and ridges, while the syenite is largely occupied by valleys. The fact that Hat Creek has eroded its valley along the west side of Mars Mountain argues against a direct connection between the outside gneiss and that forming the mountain.

The loose rock fragments on the mountain indicate a gradation from the syenite through a rock of gabbroic composition into the gneiss, but outcrops are few except near the summit. Here the gneiss is medium-grained in texture, composed of feldspar, pale blue quartz, and biotite. Under the microscope a thin section shows the rock (Spec. 218) to be essentially identical in composition with that of the outside biotite gneiss.

Gabbro.

DISTRIBUTION.

With the exception of a few dikes in the Lovingston district the gabbro is confined to the limits of the large syenite area. Most of the occurrences are near the contact with the outside gneiss, forming in places irregular areas between the gneiss and syenite. Because of insuperable difficulties, the gabbro was not differentiated from the syenite and delineated as a separate type on map, Pl. I.

The gabbro exposed on the property of the American Rutile Company, which is not far from the southeast contact, grades into the syenite on northwest side, but, owing to the depth of residual decay, its relation to the gneiss on the southeast side could not be determined. This gabbro is described in detail under the geology of the American Rutile Company's property (pages 165-168).

In the mine of the General Electric Company gabbro occurs as a dike with well-defined walls but the rock mass is very irregular in shape, widening rapidly towards the east, and it is by no means certain that it does not grade into the syenite. The lack of exposures makes it impossible to determine the true relationship of the gabbro to the other rocks except where it is exposed in the underground workings. A description of this gabbro accompanied by an analysis will be found in the discussion of the geology of this mine (pages 191-192).

MEGASCOPIC CHARACTER.

The gabbros occurring in this area range from light to dark gray in color, and medium, even-grained to porphyritic in texture, with the even-granular texture predominant. In most of them a slightly schistose structure has been developed and in some cases the rock is strongly schistose, yielding a typical uralitized gabbro-gneiss (Pl. X, fig. 3).

The principal constituent minerals of the gabbro are feldspar (plagioclase and orthoclase), pyroxene, chiefly hypersthene altered in part to hornblende, with subordinate ilmenite, quartz, rutile, and apatite. The ratio of pyroxene and its alteration product hornblende to feldspar varies, but the latter is usually dominant. Pyrrhotite and graphite are generally present, the graphite occurring in considerable quantity in some localities, especially in the gabbro of the General Electric Company's mine where the mineral also occurs in the surrounding syenite. In some of the rocks metamorphism has changed a part and in some cases all of the pyroxene to hornblende. By increase of the ore minerals, ilmenite, rutile, and apatite, and decrease of the silicate minerals, the gabbros pass through gabbro-nelsonite into nelsonite. This does not take place as a gradation in a single rock mass, but almost every intermediate phase between the two rock-types may be found at some place in the district.

MICROSCOPIC CHARACTER.

Thin sections of the gabbro show the essential minerals plagioclase feldspar of the andesine part of the series and pyroxene, chiefly hypersthene, frequently partially or wholly altered to hornblende, together with ilmenite, apatite, orthoclase, quartz, biotite, rutile, graphite, pyrite, and zircon. The principal secondary minerals are hornblende, chlorite, epidote, zoisite, leucoxene, garnet, biotite in part, and ferrite (iron stain). Not all of these minerals are present in a single thin section of the rock, and of the accessory and secondary minerals some are more frequent than others.

Feldspar, usually the most abundant constituent, includes plagioclase of the composition of andesine, containing variable microcline or orthoclase in spindle-shaped intergrowths, as the dominant variety, and a variable but smaller amount of potash feldspar, usually orthoclase, sometimes microcline. The plagioclase occurs both in tabular and formless masses or grains and not infrequently shows slightly elongated shape. It is made up of thin twinning lamellæ according to the albite law. The lamellæ are sometimes bent or curved and fractured from the effects of pressure metamorphism. The spindle-shaped intergrowths of microcline and orthoclase are usually parallel to the twinning lamellæ after the albite and pericline laws. In a thin section of the typical rock (Spec. 19) six measurements made on the rhombic section of the plagioclase gave 17.2°, 18.5°, 17°, 19°, 18°, and 18°, corresponding to range in composition from $Ab_{63}An_{37}$ to $Ab_{61}An_{39}$, with an average of $Ab_{62}An_{38}$. Neither zonal structure nor graphic intergrowths were observed. Plate XX, fig. 1, is a photomicrograph of a thin section (Spec. 19).

Orthoclase, including microcline, is always present but in greatly varying amounts. It is occasionally observed as formless grains, but its principal occurrence is as spindle-shaped intergrowths with the dominant feldspar, andesine, identical with the intergrowths in the syenite and the intermediate facies between the gabbro and syenite (Pl. VIII, fig. 2). In this mode of occurrence andesine usually forms the host and microcline or orthoclase the roughly parallel, long, and narrow spindles. Microcline is variant but as spindle-shaped intergrowths with andesine it is probably more abundant than orthoclase.

The feldspars, especially plagioclase, usually contain inclusions which are so abundant in some cases as to largely obscure the substance of the host. The inclusions are of divers kinds and shapes. Long, narrow-shaped bodies, probably feldspar (orthoclase or microcline), are noted sometimes in two sets which cross at a definite angle. Transparent and colorless grains irregularly rounded to rectangular outlines of probably feldspar of lower refractive index than the matrix are shown. Dustlike particles, the identity of which was indeterminate, apatite, and rutile occur.

Pyroxene, chiefly hypersthene, together with its alteration product hornblende, next to feldspar, is the most abundant constituent. The change of pyroxene to hornblende is most extensive and the hornblende is most abundant in the thin sections of gabbro showing the greatest dynamometamorphism. In some thin sections secondary hornblende is more abundant than pyroxene. The pyroxene occurs in subhedral crystals flattened or prismoid and in irregular grains. It is of light to moderate color, pleochroic, possesses good cleavage, and carries inclusions which frequently impart a submetallic or bronze-like lustre. Irregular fractures are not infrequent. Pleochroism Y = greenish, X = reddish-yellow, Z = reddish-brown. Besides inclusions of apatite, magnetite, and hairlike forms, probably rutile, the hypersthene frequently contains brown inclusions often regularly arranged and rectangular in outline, which give to it a rather distinctive bronze-like lustre. Hornblende is the commonest alteration product of the pyroxene. The hornblende shows the usual optical characters indicative of secondary origin. It is usually a pale blue-green, fibrous and frayed-out, and pitted around the borders. It frequently shows columnar and irregular platy masses, with pronounced pleochroism in the deeper colored forms. Occasional pieces show the two prismatic cleavages mottled by inclosures of feldspar. In some cases the hornblende shows partial alteration to chlorite, sometimes accompanied by the separation of grains of black oxide of iron distributed through the substance of the chlorite.

Biotite is present in many of the thin sections, ranging from a few scattered shreds in some to a goodly proportion in others. It occurs in single shreds and aggregates, brown in color, strongly pleochroic, and in many cases is partially or entirely altered to chlorite.

Quartz is quite generally present but in variable amount. It is most abundant in sections of the transitional type and like that of the syenite it contains inclusions of rutile needles. It occupies distinct areas, frequently shows mashing and optical disturbance, and, besides hairlike inclusions of rutile, it carries inclusions of graphite and indeterminate dustlike particles.

Ilmenite, variable in amount, is usually present in considerable quantity as euhedral and anhedral crystals of small and large size. It is frequently altered peripherally to leucoxene, in many cases completely altered, in others a nucleal particle of the ilmenite remains surrounded by leucoxene, with nearly all gradations between these extremes.

Apatite, in varying amount, occurs as separate individuals of euhedral and subhedral form and as inclusions in the principal minerals. It is usually fresh, without inclusions, but is sometimes fractured. Rutile is frequent as needle-like inclusions, and was observed in several thin sections in occasional formless grains. Garnet, as nearly colorless anhedra exhibiting fractures, is present in several thin sections.

Graphite was identified in a number of the thin sections, as inclusions in the quartz, as small, irregular areas associated with the principal minerals along lines of fracture and boundaries (sutures) between the minerals, and to some extent in their substance in a manner suggestive of replacement. It is probably most frequently associated with the light-colored minerals. The relations are such as to suggest that the graphite in part at least is primary. Epidote and zoisite occur in many thin sections as secondary minerals derived from feldspar. The former is probably the most abundant, and when zoisite is present, they are closely associated as an epidote-zoisite aggregate, the individuals being differentiated by their contrasted double refraction. Pyrite is sometimes present but always in small amount. It is intimately associated in one section with graphite.

CHEMICAL COMPOSITION AND CLASSIFICATION.

The chemical composition of the gabbros is shown in the table of analyses below. The analyses were made on specimens of gabbro collected along the southeast border of the syenite mass in the vicinity of Roseland, and the American Rutile Company's quarries, and in the mine of the General Electric Company.

Analyses of gabbros from Nelson County, Virginia.

(WM. M. THORNTON, JR., *Analyst.*)

	I	II	III	IV	V
SiO_2	50.99	51.08	54.80	57.74	53.65
Al_2O_3	12.40	16.45	14.28	18.90	15.51
Fe_2O_3	2.10	0.84	3.08	1.42	1.86
FeO	11.80	10.08	7.55	3.87	8.33
MgO	4.09	6.95	2.52	3.52	4.27
CaO	6.46	5.57	6.57	6.42	6.26
Na_2O	2.38	3.49	2.61	3.74	3.06
K_2O	2.19	1.28	2.00	1.72	1.80
H_2O-	0.12	0.08	0.16	0.06	0.11
H_2O+	1.21	0.51	1.23	1.11	1.02
TiO_2	4.66	4.44	4.15	1.24	3.62
P_2O_5	1.86	0.14	0.70	0.28	0.75
MnO	0.11	0.08	0.02	0.02	0.06
CO_2	Trace	Trace	Trace	Trace	Trace
S	Trace	Trace	0.02	0.20	0.05
	100.37	100.99	99.69	100.19	100.31
Specific gravity	......	2.977	.....	......	......

I. Gabbro dike exposed in north cross-cut on the 100-foot level, 50 feet from shaft, General Electric Co.'s mine, 1.5 miles northwest of Rose's Mill. Width of dike where sampled 8 feet; strike S. 76° E; dip 55° N.

II. Gabbro in Roseland-Arrington road, near Mr. Adams's house, about 100 yards south of Roseland post-office. Cut by diabase dike yielding analysis in column II, p. 158.

III. Gabbro along east side of Tye River, 525 feet south of American Rutile Co.'s south quarry. Gabbro shows gneissic structure.

IV. Gabbro along east side of Tye River, about 95 feet north of III; specimen collected on east side of and near contract with diabase dike 8 feet wide yielding analysis in column III, p. 158. Gabbro gneissic in structure.

V. Average of I, II, III, and IV.

The microscopical character of the gabbro yielding the analysis in column I is given on page 192, and the analyses in columns III and IV on pages 166-167.

The sample used for analysis II was from an exposure of gabbro on the county road between Roseland and the mill of the American Rutile Company. It is a medium gray, even-granular rock, massive in thin section but showing very slight schistose structure in the hand specimens. Under the microscope, a thin section shows the principal minerals to be pyroxene chiefly hypersthene, altering peripherally to hornblende, plagioclase feldspar (andesine) of the composition $Ab_{62}An_{38}$ containing variant microcline in spindle-shaped intergrowths usually oriented parallel to the twin lamellæ after the albite and pericline laws, a little microcline, ilmenite altering to leucoxene, rutile as hairlike inclusions and separate grains, apatite, and inclosures of quartz in the feldspar. A photomicrograph of a thin section of the rock is reproduced in Pl. XX, fig. 1.

The norms calculated from the analyses above are as follows:

Norms corresponding to analyses of gabbro on page 95.

	I	II	III	IV
Quartz	8.94	.....	15.54	9.72
Orthoclase	12.79	7.23	11.68	10.01
Albite	19.91	29.34	22.01	31.44
Anorthite	16.68	25.58	21.41	29.79
Diopside	3.43	0.92	5.78	0.46
Hypersthene	21.05	27.53	7.90	12.30
Magnetite	3.02	1.16	4.41	2.09
Ilmenite	8.82	8.36	7.90	2.43
Apatite	4.03	0.31	1.55	0.62
Pyrite	.....	.....	.....	0.36
H_2O	1.33	0.59	1.39	1.17
	100.00	101.02	99.61[a]	100.34

[a] Includes MnO, .02; S, .02.

No.	Symbol	Name
I.	′III. 4′. 3. ′4.	Vaalose.
II.	′III. 5. 3′. 4.	Andose-camptonose.
III.	II. 4. 3. ′4.	Tonalose.
IV.	′II. ′5. 3′. 4.	Hessose-andose.

Attention is directed in the composition of the gabbros to the variable but reasonably high SiO_2 and K_2O, indicated in the thin sections by the presence usually of quartz and potash feldspar (microcline and orthoclase) as occasional separate grains, but chiefly as spindle-shaped intergrowths with the dominant feldspar (andesine). The analyses are further noteworthy for the uniformly high percentage of TiO_2 and to a less extent P_2O_5, a characteristic feature in the composition of the rocks of this area that is discussed elsewhere in this report. Excepting the ferromagnesian mineral, pyroxene, whose exact chemical composition is unknown, there is reasonably close agreement in the norms and the actual mineral composition of the gabbros.

Like the diabase (pages 155-160), the albite-anorthite ratio of the gabbros, calculated from the analyses, corresponds very closely in each case to a plagioclase feldspar having the composition Ab_1An_1.

DETAILS OF OCCURRENCES.

The brief descriptions which follow below will give a general idea of the character and occurrence of the gabbro in other localities within the area:

Blasting for a roadway on the farm of Major Boyd, three-quarters of a mile southeast of Bryant, furnished a fresh exposure of gabbro (Spec. 86). It is an even-granular, light gray rock slightly schistose in structure, and composed of the following minerals given in the order of their relative abundance: White feldspar, dark green pyroxene, irregular grains of light pink garnet, graphite, quartz, ilmenite, and pyrrhotite. Examined in thin section, under the microscope, the principal minerals are feldspar (plagioclase near andesine, orthoclase and microcline chiefly as intergrowths with andesine), pyroxene chiefly hypersthene, ilmenite, garnet, quartz, a little graphite, pyrite, and zircon (?). Rutile and apatite occur as inclusions. The secondary minerals are kaolin, muscovite, and leucoxene. Quartz, present in small amount, contains inclusions of rutile needles and shows wavy extinction. Some of the plagioclase feldspar shows bent and curved lamellæ which are broken across in some cases.

On the farm of A. W. Campbell, about 1.5 miles south of Bryant, there occurs a gabbro (Spec. 93) very similar to that described above except that it contains less graphite and a little more quartz. It contains occasional bands that are coarsely crystalline in texture, the individual minerals averaging 1 to 2 cm. in diameter. This coarse portion of the rock is composed for the most part of feldspar, pyroxene, and ilmenite. Considerable secondary pyrite is present as a coating on the other minerals.

Microscopically, a thin section of this rock indicates that it represents a probable transitional facies between the syenite and the gabbro proper. The evidence is based chiefly on composition. The principal feldspar is an intergrowth of andesine with orthoclase (microcline), in which andesine is the host and orthoclase (microcline) the spindles, giving the structure but reversing the order of species in microperthite. Much of the quartz contains abundant inclusions of rutile needles. The principal minerals are feldspar (chiefly andesine-orthoclase (microcline) intergrowths, separate individuals of plagioclase near andesine, and some microcline), pyroxene, chiefly hypersthene, quartz containing hairlike inclusions of rutile, ilmenite altering to leucoxene, some graphite, pyrite, and apatite inclusions. Partial granulation of the feldspar and quartz is indicated, and the quartz shows wavy extinction. Plate VIII, fig. 2, shows a photomicrograph of the thin section.

There is an outcrop of gabbro (Spec. 220) near the south side of the county road, 1.75 miles south of Bryant. The rock is dark gray in color and contains feldspar, pyroxene, ilmenite, and a little quartz. From the large percentage of ilmenite present the rock resembles gabbro-nelsonite, and it may grade into it as there are outcrops of the latter (Spec. 219) within a few yards (page 145). Much ilmenite sand is concentrated on the surface in places. Microscopically the chief minerals are the same as in specimen 93, page 97, except that microcline is less in amount, and though quartz is present in goodly quantity very few rutile inclusions were observed. The character of the feldspar is the same for the two thin sections, and like specimen 93 this rock represents a probable transition facies between the syenite and the gabbro. Pyroxene, chiefly hypersthene, and ilmenite are present in their usual amount; the former (pyroxene) is partly altered to pale green fibrous hornblende, and ilmenite partly to leucoxene.

On the farm of Cubus Whitehead, about 1.75 miles southeast of Lowesville, there is much gabbro float (Spec. 116). The rock is porphyritic in texture, which on weathering gives a pitted surface. It is dark gray in color and is composed of irregular-shaped feldspar phenocrysts about 0.75 cm. in diameter imbedded in a ground-mass of hornblende, feldspar, quartz, and ilmenite. Much rutile, in pieces as large as a walnut, is intermingled with the gabbro float. In thin section, under the microscope, the rock is seen to be composed of feldspar chiefly plagioclase (andesine), pale green fibrous hornblende, quartz, ilmenite, a little apatite, and an occasional grain of zircon (?). Feldspar shows alteration into muscovite and kaolin, and ilmenite into leucoxene. Mashing from dynamo-metamorphism is manifested in some of the minerals in thin section.

An exposure of gabbro (Spec. 125) is shown in the bluff that borders the south side of Piney River opposite the mine of the General Electric Company. It is a dark greenish-brown rock, considerably altered, but composed for the most part of feldspar, hornblende, and chlorite. When examined in thin section, under the microscope, the principal minerals are seen to be feldspar (plagioclase and orthoclase (microcline)), pyroxene largely altered to hornblende, quartz, biotite, ilmenite, and inclusions of rutile and apatite. Secondary pale green hornblende, in columnar and irregular platy fibrous form, is the most abundant mineral. Feldspar and quartz show granulation and the latter wavy extinction. Much of the ilmenite is largely altered to leucoxene.

On the northwest bank of Tye River, about 1.25 miles east of Rose Union, a gabbro dike (Spec. 137) is exposed close to the contact between the rutile-bearing rocks and the outside gneiss, but probably lies within the latter. The dike is about 12 feet wide and has a strike of N. 45° E. It is a fine-grained, dark gray rock, schistose in structure, composed of feldspar, biotite, hornblende, blue quartz, and ilmenite. The large amount of biotite present is unusual for the gabbros of this area, and the rock may represent a border phase intermediate between the outside gneiss and the gabbro. Microscopically the principal minerals are pale green fibrous hornblende, brown biotite, quartz, ilmenite, apatite, rutile, zircon, calcite, and leucoxene. Most of the minerals are secondary with no trace of the original minerals from which they were derived. The quartz shows pronounced wavy extinction and granulation. Feldspar was not identified.

A small dike of dark-colored, disintegrated rock crosses the county road a quarter of a mile northeast of Roseland. A piece of nearby float (Spec. 34), probably derived from this dike, is composed largely of pyroxene, with lesser amounts of feldspar, pyrrhotite, and ilmenite. Examined in thin section under the microscope the principal minerals are seen to be pyroxene (monoclinic and orthorhombic forms), some intermediate plagioclase (andesine), less orthoclase, a little quartz, ilmenite, and occasional grains of pyrite. Much pale green fibrous hornblende, derived from the alteration of pyroxene, is present. Pyroxene and its alteration product make up more than 75 per cent of the thin section. Plagioclase feldspar (andesine), present in limited amount as small anhedral grains, is probably the next most abundant mineral. The alteration of pyroxene to hornblende is frequently accompanied by the formation of much black iron oxide as inclusions in the hornblende substance. Inclusions of apatite were noted in the quartz.

A rock that appears to be intermediate between gabbro and syenite outcrops half a mile northeast of Rose Union (Spec. 131). It is gneissic in structure, showing imperfect banding of the light- and dark-colored minerals. White feldspar is dominant with dark green pyroxene, ilmenite, quartz, and a little apatite as the other constituents. On weathering the pyroxene and ilmenite stand out in relief. Many small pieces of ilmenite and rutile, probably weathered from this rock, are found scattered over the surface in this vicinity. Microscopically, the rock appears to be a transitional type between gabbro and syenite. The principal minerals are feldspar (plagioclase of andesine composition containing intergrowths of microcline), orthorhombic pyroxene (hypersthene), a few grains of quartz, ilmenite, and some rutile. The feldspars usually carry inclusions, among which are apatite and occasional rutile; show some alteration, and are of similar composition to those of the syenite. Quartz shows optical disturbance and contains occasional hairlike inclusions of rutile. The pyroxene is of the same general character, and contains similar brown inclusions of elongated and rectangular outline, as that described above in the gabbro. It shows alteration peripherally and along cracks to a fibrous green mineral, probably hornblende. Rutile occurs as grains of reddish-brown color and is less plentiful than ilmenite, both of which show some alteration peripherally to leucoxene.

Near the bend in Tye River, on the east side and close to the contact with the outside gneiss, about one mile northwest of Roseland, is an exposure of uralitized gabbro in such an advanced stage of weathering as to render it almost impossible to obtain a fresh specimen. Study of a thin section under the microscope likewise shows the rock to be greatly altered. The principal minerals are greenish-brown hornblende (uralite) derived from pyroxene, soda-lime feldspar (andesine), irregular shreds of brown biotite, a sprinkling of large grains of apatite, much magnetite or ilmenite rimmed with leucoxene as an alteration product, and a single large grain of brown rutile. The feldspar exhibits marked alteration chiefly to sericite, much of which is discolored a dirty brown from iron oxide which almost obscures the substance of the original mineral. (See Pl. VIII, fig. 2.)

Nelsonite.

NAME.

Nelsonite is the name given to a group of high titanium-phosphorus-bearing rocks of igneous origin, occurring in dikelike bodies of varying size and irregular shape in the Amherst-Nelson counties region, Virginia, and to a less extent farther southwest on the northwest slope of the Blue Ridge in Roanoke County (pages 241-245). The name was first proposed by the senior writer[a] for the dikelike bodies in these counties composed normally of the ore minerals ilmenite and apatite, and named for Nelson County, Virginia, where the rock was first found. Subsequent detailed work by the writers[b] for this report in Nelson and Amherst counties has resulted in extending the name to include several closely related and associated varietal forms of the rock occurring in the same area, based on differences in mineral composition (pages 103-104). The varieties included under nelsonite as now defined are described in detail in the following pages 100-155. Ilmenite nelsonite to which the name was first applied is the normal and most abundantly occurring variety of nelsonite.

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[a] Watson, Thomas L., Mineral Resources of Virginia, 1907, p. 300.

[b] Watson, Thomas L., and Taber, Stephen, Bull. No. 430, U. S. Geol. Survey, 1909, Pt. I, p. 206.

DISTRIBUTION.[a]

Nelsonite occurs in the form of dikelike bodies both in the Roseland and Lovingston districts. Reference to the map (Pl. I) shows that, in the Roseland area, the nelsonite dikes usually occur not far from and distributed along the border portion of the syenite, with most of them confined to the syenite area, but some are found in the outside gneiss near the contact. The rutile-bearing variety of nelsonite is confined within the limits of the syenite, but the ilmenite nelsonites free from rutile, while more numerous within the syenite area, are also found in the outside gneiss near the contact; and they occur in the vicinity of Lovingston and on Davis Creek. Magnetite nelsonite is found in the surrounding gneiss, but does not occur in the syenite.

MEGASCOPIC CHARACTER.

The varietal forms included under nelsonite are rocks of holocrystalline and even-granular texture, of dark color, and are composed of the principal ore minerals apatite with ilmenite or rutile, or both, and in some cases magnetite. Occasionally porphyritic texture is developed in the rock when apatite forms the porphyritically developed (phenocryst) mineral. The ratio of the ore minerals is subject to rather wide variation, usually the dark titanium mineral (ilmenite or rutile, occasionally magnetite) being in excess of apatite. Subordinate silicate minerals (chiefly hornblende and biotite) may or may not occur; in a few cases either hornblende or biotite is present in sufficient amount to be designated a principal constituent. Pyrite is an almost constant minor mineral in the Amherst-Nelson counties rocks, but is essentially absent from the similar types of the Roanoke County area, possibly because of oxidation, as it was impossible to obtain perfectly fresh material from the latter area. In most cases the granularity of nelsonite is remarkably uniform, the essential minerals being developed in grains and crystals of approximately equal size and of nearly equal dimensions in all directions. The individual minerals usually range from 1 mm. to 3 mm. in diameter, rarely less than 1 mm. Plate XII, fig. 2, a photograph of a polished specimen of ilmenite nelsonite, shows the texture of the normal rock.

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[a] In a recent trip across the Blue Ridge in Virginia, from Arrington to Vesuvius, by way of Roseland and the Irish Creek tin area, Messrs. Hess and Larsen, of the U. S. Geological Survey, collected specimens of nelsonite on top of the Blue Ridge, 0.5 mile north of Montebello, near the headwaters of South Fork of Tye River. According to the Lexington topographic sheet, Montebello is 8.5 miles northwest of Massie's Mill, and the locality from which the specimens were taken is about 7 miles beyond the northwest limits of the area mapped and described in this report.

Thin sections of the rocks show the principal minerals to be ilmenite, apatite, a much altered ferromagnesian mineral probably pyroxene, and a few scattered grains of zircon (?), together with the usual alteration products. The specimens are not fresh but, with the exception of zircon, the minerals mentioned above in thin section are readily recognized megascopically.

SIZE, SHAPE, AND STRUCTURE OF THE BODIES.

Nelsonite, including the several varietal forms based on differences in mineral composition noted below, is the most abundant dike rock occurring in the district. The sizes of the dikes vary greatly. Several of the more persistent ones may be traced along their strike for considerable distances. In length the dikes range up to 2,000 feet, as exposed on the surface, but lengths of several hundred feet are more common; in width from a few inches up to 65 feet or more, and in depth, while none of them have been prospected for more than 100 feet below the surface, they undoubtedly extend much farther.

Though dikelike in character the nelsonite bodies are subject at times to considerable irregularity in outline. Several of them are lenticular in shape and where the more continuous bodies have been exposed for some distance they are found to pinch and swell both in dip and along the strike. In some instances the dikes before pinching out split into several parallel stringers. They trend in almost every conceivable direction, but northeast and southwest is the dominant direction of strike.

Usually the boundaries between the dikelike bodies of nelsonite and the enclosing rock are sharply marked, but in places there is a gradation between the two, which is especially true of the rutile nelsonites. As a rule the nelsonite bodies appear to conform to the structure of the inclosing rock when schistose, but in places the correspondence seems far from being exact.

The prevailing texture of nelsonite is even-granular, usually with remarkable uniformity in granularity and composition of the rock from center to walls of the dike. In places in some of the dikes, especially rutile-nelsonite, at the General Electric Company's mine near Rose's Mill, there is an appearance of imperfect banding or crustification of the titanium minerals and apatite, but this is exceptional and can not be interpreted as indicating vein origin as against igneous origin for these bodies.

The nelsonite bodies are usually cut by several sets of rather closely spaced joints, so that the rock breaks into small blocks of rhomboidal

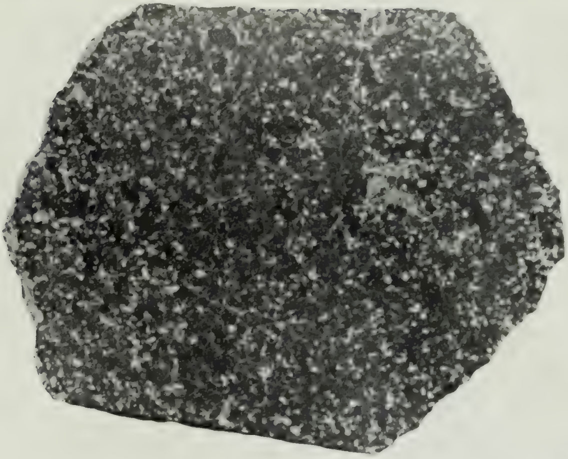


Fig. 1.—Polished section of ilmenite nelsonite showing texture. General Electric Company's mine, Nelson County. Light nearly white areas apatite, dark areas ilmenite chiefly. Natural size.

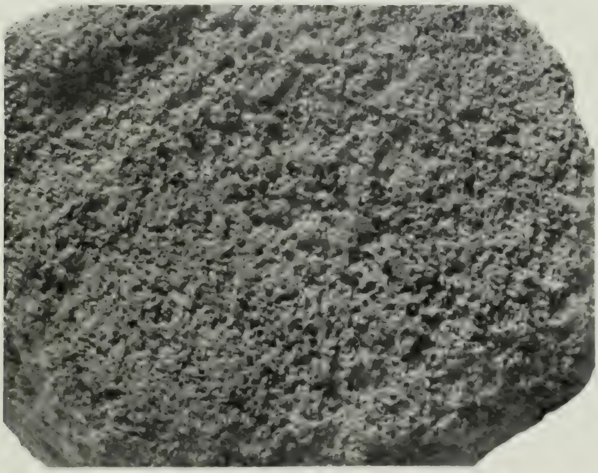


Fig. 2.—Surface section of ilmenite nelsonite showing characteristic pitted surface from differential weathering by solution and removal of apatite, leaving an outer spongelike mass of ilmenite. General Electric Company's mine, Nelson County. Natural size.

FRESH AND WEATHERED ILMENITE NELSONITE.

shape when struck with the hammer. In consequence the surface is frequently littered with blocks broken from the rock in place. So far as can be ascertained from exposures faulting of the nelsonite bodies appears to be rare. It has been observed only in the ilmenite nelsonite dike on the Hight place, about 1.75 miles a little west of north from Roseland, but from field relations it is inferred in several places, especially the nelsonite occurring on the Warwick tract where is opened the General Electric Company's mine (page 176). The horizontal displacement is only slight in amount as may be seen in Pl. XIV, a photograph taken of the dike as exposed by a shallow cut.

MINERAL COMPOSITION.

Variation in mineral composition gives rise to several varietal forms of nelsonite, the normal one of which is an even-granular mixture composed essentially of ilmenite and apatite. Ilmenite or apatite may be the dominant mineral but the former is usually in excess. At several localities, notably at the General Electric Company's mine and the openings on the Bourne place, near Rose's Mill, and on the Giles tract, near Roseland, ilmenite is largely replaced by rutile, the rock being composed chiefly of rutile and apatite, with some ilmenite. The ratio of titanium minerals to apatite varies, the rocks ranging from one composed largely of the dark minerals with but little apatite to one composed practically of all apatite. The apatite in the several varietal forms of nelsonite recognized is a fluor-apatite, as is indicated in the analyses on pages 147 and 206. Chlorine is often present in traces, and in one analysis sufficient manganese was found to designate the mineral mangan-apatite.

Magnetite replaces the titanium minerals in some of the dikes occurring in the vicinity of Lovingston and elsewhere beyond the limits of the rutile area proper, accompanied by apatite and biotite. Biotite, partly altered to chlorite, is an important constituent in some of the nelsonites in the Lovingston district and in the Hat Creek section of the Roseland district. In several occurrences in the Lovingston district, and near Rose's Mill in the Roseland district, hornblende with apatite, the former largely in excess and in the Rose's Mill area altered to chlorite, are the dominant constituents in the rock.

In the different varieties of nelsonite the percentage of apatite seems to vary directly with the titanium content; it is greatest in the rutile and ilmenite nelsonites, much less in the magnetite and biotite varieties, and probably least in the hornblende nelsonites.

A second facies of the rock nelsonite is observed in parts of the area, which shows a predominance of the dark ferromagnesian minerals, more especially hypersthene and secondary hornblende, over the ore minerals. This facies of the rock also contains essential feldspar, chiefly plagioclase with a little orthoclase, and occasional quartz. It is composed chiefly of pyroxene (hypersthene) and feldspar (plagioclase principally), apatite, and ilmenite or magnetite. In some places the pyroxene is partly or entirely altered to hornblende. For this facies of the rock the name gabbro-nelsonite was proposed by the writers, and is described in detail on pages 138-145. It occupies an intermediate position between gabbro and nelsonite.

VARIETIES.

The variation or range in mineral composition of nelsonite described above gives rise, according to the older terminology, to the following varietal forms of the rock, which are separately described on pages 106-155: (a) Ilmenite nelsonite, (b) rutile nelsonite, (c) magnetite nelsonite, (d) biotite nelsonite, (e) hornblende nelsonite, and (f) gabbro-nelsonite.

The prefixes ilmenite, rutile, magnetite, biotite, and hornblende denote special richness of the rocks in these minerals. The prefix gabbro denotes a rock intermediate in composition between gabbro and nelsonite.

The dikes of nelsonite, composed essentially of the ore minerals, have been prospected at many places in the area, chiefly near Roseland, Bryant, and Lovingston, for phosphate (apatite), and near Rose's Mill, on Piney River, by the General Electric Company for rutile.

GENERAL MICROSCOPIC CHARACTERS.

When examined in thin sections under the microscope the variation in mineral composition, which gives rise to the recognized varietal forms of the rock, becomes readily apparent. These are enumerated under "Varieties" on page 104, and the microscopic characters of each separately described in detail, so that it is unnecessary to repeat the descriptions here. Only a brief general summary of texture and mineral composition, developed from microscopic study, will be given under this heading.

The texture of nelsonite varies from granitoid to porphyritic, according to variety. In granularity the range is from medium to fine-grained rocks. In those types of the rock exhibiting granitoid texture, the chief minerals are usually formed in grains of approximately equal size and of nearly equal dimensions in every direction. In the porphyritic types, the phenocrysts may be either plagioclase feldspar, as in the gabbro-nelsonites, or apatite as in several of the nelsonites proper (Pl. XIII, fig. 2).

In thin sections the mineral composition varies with respect to the chief constituents according to types of the rock considered. Variation, however, is in general more one of quantity than of kind, for the dominant minerals in one type become the subordinate ones in another, and vice versa. In nelsonites proper the rock is composed of a granular mixture of the ore minerals in which apatite though variable in amount is alike common to each type, with ilmenite, rutile, or magnetite, as the second chief constituent. Silicate minerals are frequently sparingly developed, increase in which marks the passage into other types composed of a mixture of silicate and ore minerals, the former usually being in excess. Hornblende and gabbro-nelsonites are representatives, the latter connecting the gabbros with the nelsonites proper. Nearly all gradations between types may be observed.

Disregarding types, thin sections of nelsonite proper are shown microscopically to be composed of the minerals ilmenite, rutile, magnetite, and apatite, together with the very minor accessories hornblende, biotite, quartz, and titanite. Leucoxene and osteolite are the commonest secondary minerals, with calcite, chlorite, and hornblende sometimes occurring. The sulphides, pyrite and pyrrhotite, especially pyrite, are usually present, sometimes in considerable quantity.

In the silicate-bearing types of nelsonite orthorhombic pyroxene (hypersthene), hornblende, biotite, and plagioclase feldspar (andesine), together with apatite, ilmenite, magnetite, and occasionally a little rutile, are the principal minerals. An occasional quartz grain occurs. The usual secondary minerals derived by alteration from these may be present.

Detailed petrographic descriptions of each type of nelsonite are given in the pages which follow, and to which the reader is referred.

WEATHERING.

Weathering has produced marked changes on the outcrops of the nelsonite bodies, breaking them down mechanically and producing more or less chemical change. As the result of these changes, which extend for many feet below the surface, the rock is softened and crumbles readily under the hammer. The apatite, when not removed through solution at the surface, becomes lustreless and chalklike in character principally through hydration. The titanium minerals are more resistant chemically and apparently have suffered only slight effects through hydration and solution. More or less discoloration from iron oxide staining is frequently observed, and in some cases the formation of a new compound of bluish-green color, probably the hydrous ferrous phosphate, vivianite, is observed. The weathered surfaces of much of the rock are characteristically pitted from the complete removal of apatite. (See Pl. XII, fig. 2.)

Ilmenite Nelsonite.

DISTRIBUTION.

The rocks described under this head are with very few exceptions limited to the border portions of the syenite area, and none are found in the central portion or near the south end. A few occur in the outside gneiss in the Hat Creek section close to the northwest border of the syenite, but these contain a little biotite or chlorite though not sufficient to place them in a second group. They are most plentiful in the Hat Creek valley at the north end of the area and along the southeast border in the vicinity of Tye and Piney rivers.

MEGASCOPIC CHARACTER.

The normal type of the rock nelsonite is ilmenite nelsonite, which is an even-granular mixture composed essentially of ilmenite and apatite. It is a massive dark-colored rock of salt and pepper appearance, the individual grains of ilmenite and apatite averaging about 2 cm. in diameter. (See Pl. XII, fig. 1.) The relative proportion of the two minerals varies, but ilmenite is generally dominant and usually averages between 60 and 80 per cent. The apatite occurs in rounded individuals, 1 to 2 cm. in diameter, which frequently show roughly hexagonal cross-sections, while ilmenite surrounds the apatite grains, filling the interstitial spaces and binding the mass together. Wherever observed, the normal ilmenite nelsonite is remarkably uniform in texture and mineral composition from center to walls of the bodies. Weathered specimens from which the apatite has been removed by solution exhibit a cellular, spongelike or honeycombed texture. (See Pl. XII, fig. 2.)

The sulphides, pyrite and pyrrhotite, are usually present when the rock is fresh. They may occur both as a constituent of the rock and as a coating on the surfaces of joint planes which intersect the ore-bodies. In the latter occurrence the sulphides are of later or secondary formation. In the nelsonite bodies of the General Electric Company's mine, on Piney River, much secondary pyrite has been deposited as a coating on joint planes, but where the joints cut segregations of pure apatite very little pyrite is found. Quartz is seldom observed as a megascopic constituent of the normal ilmenite nelsonite, and when present is usually confined to the border portions of the body. Biotite and secondary hornblende derived from pyroxene are sometimes present as minor constituents.

MICROSCOPIC CHARACTER.

The microscopic petrography of normal ilmenite nelsonite is quite simple. Under the microscope thin sections show a rock of medium- to fine-grained, even-granular texture, composed of a mixture of the essential minerals ilmenite and apatite, together with a few primary and secondary minor accessory minerals, some of which are identifiable in the hand specimens. In most cases the granularity of the rock is remarkably uniform, the size of grains of the two chief minerals ranging from 1 mm. to 3 mm., but in some cases the individual grains average less than 1 mm. in size. The two essential minerals are developed in grains of approximately equal size and of nearly equal dimensions.

Of the two chief minerals, ilmenite is usually in excess of apatite, the ratio of the two varying within rather wide limits, but in several thin sections the two minerals roughly approximate nearly equal proportions. Ilmenite is usually developed in formless grains, sometimes shows partial crystal boundaries, and often exhibits about the borders some alteration to nearly colorless or light gray leucoxene.

The following analysis of ilmenite separated from typical ilmenite nelsonite at the General Electric Company's mine shows the chemical composition of the mineral:

Analysis of ilmenite from nelsonite, General Electric Company's mine.

(WM. M. THORNTON, JR., *Analyst.*)

	Per cent.
TiO_2	54.44
FeO	40.94
MnO	0.52
Fe_2O_3	4.26
SiO_2	0.34
Cr_2O_3	0.07
V_2O_5	0.29
SnO_2	Trace
Cb_2O_5	None
Ta_2O_5	None
H_2O	None
	100.86
Specific gravity	4.713

The melting point of the ilmenite showing the above chemical composition, as measured by the Bureau of Standards, is 1390° C.

Apatite, the next most abundant mineral, of slightly bluish-gray color when fresh, manifests a strong idiomorphic tendency although often developed in nearly formless grains of rounded outline. Some of the crystals exhibit faintly developed cleavage, and abundant minute inclusions of an indeterminate character are sometimes observed. In some thin sections much of the apatite shows more or less alteration to the earthy form osteolite, the stage of decay being so advanced in many of the crystals as to render them entirely opaque. As indicated in the analyses of the rock on page 109, the mineral is the variety flour-apatite, but frequently traces of chlorine also occur.

The general tendency of the apatite to develop in grains with crystal boundaries and its inclosure in part by ilmenite at times, suggest that apatite crystallized in some cases at least in advance of the ilmenite. In some thin sections, however, the relations of the two minerals strongly indicate that they have formed more nearly simultaneously, mutually interfering with each other.

An analysis of apatite from one of the segregated bands in nelsonite (Spec. 154) at the General Electric Company's mine gave the following results:

Analysis of apatite from nelsonite, General Electric Company's mine.

(WM. M. THORNTON, JR., *Analyst.*)

	Per cent.
CaO	54.37
MgO	0.53
P_2O_5	41.30
F	2.50
Cl	0.10
SiO_2	0.33
TiO_2	0.20
Fe_2O_3	0.61
H_2O	0.19
	100.13
Excess oxygen	1.07
	99.06

As indicated by the analysis the mineral is the fluor-apatite variety, containing a very small amount of chlorine, which is in accord with the nelsonites in general, as shown by an examination of the table of analyses on page 147.

The Bureau of Standards determined the melting point of the apatite represented by the above analysis to be 1645° C.

Of the minor minerals present in the rock the sulphides, pyrite and pyrrhotite, especially the former, are probably the most abundant. In some specimens sulphides will make up several per cent of the rock mass. They are developed both in formless grains and in crystals, and present no unusual characters. Occasional shreds of brown biotite occur. Colorless to pale blue-green hornblende of secondary origin, probably derived from pyroxene, though no trace of the latter mineral was observed, is sparingly developed as large and small individuals in some of the thin sections studied.

An occasional grain of blue quartz, containing needlelike inclusions of rutile and otherwise similar to that of the syenite, is noted in some of the thin sections. When observed megascopically in the rock the quartz has been found limited to the border portions of the nelsonite bodies close to the contact with the inclosing rock. Sporadic crystals of primary titanite are found in several thin sections, and graphite was identified in at least one section.

The secondary minerals include hornblende, biotite, leucoxene, and osteolite.

CHEMICAL COMPOSITION AND CLASSIFICATION.

The chemical composition of ilmenite nelsonite is shown in the four analyses given below, made on specimens collected in the vicinity of Roseland and the General Electric Company's mine, Nelson County, Virginia.

Analyses of ilmenite nelsonite from Nelson County, Virginia.

(Wm. M. Thornton, Jr., *Analyst.*)

	I	II	III	IV
TiO_2	42.84	41.46	37.68	37.00
P_2O_5	6.89	7.59	12.48	13.08
Fe_2O_3	11.12	15.59	2.70	4.31
FeO	27.93	23.57	29.14	26.52
CaO	8.34	9.03	16.05	16.33
MgO	0.72	0.50	0.50	1.11
MnO	0.18	0.26	Trace	0.38
SiO_2	0.70	1.65	......	0.57
H_2O-	0.15	0.53	0.03	0.09
H_2O+	0.58	0.87	......	0.59
F	0.21	0.17	1.03	0.98
Cl	0.01	Trace	Trace	Trace
CO_2	Trace	Trace	Trace	Trace
S	......	......	1.17	1.45
	99.67	101.22	100.78	102.41
Less O..................	.09	.07	.72	.79
	99.58	101.15	100.06	101.62
Specific gravity	......	......	......	4.073

I. Ilmenite nelsonite dike on Shelton farm about 1 mile northwest of Roseland.

II. Ilmenite nelsonite dike on Hight place about 1.75 miles west of north from Roseland. (See Pl. XIV.)

III. Ilmenite nelsonite from ore dump at General Electric Co.'s mine, 1.75 miles northwest of Rose's Mill. Probably taken from No. 1 vein in the adit level.

IV. Ilmenite nelsonite from ore dump at General Electric Co.'s mine, 1.75 miles northwest of Rose's Mill.

Norms corresponding to analyses of ilmenite nelsonite on page 109.

	I	II	III	IV
Quartz	.....	1.65	.....	.....
Hypersthene	1.10	.....	.....	.....
Olivine	.....	.....	.....	1.26
Hematite	11.04	15.38	2.72	4.32
Ilmenite	58.98	49.86	60.65	52.46
Rutile	11.76	15.20	5.76	9.36
Apatite	16.13	17.18	29.57	30.91
Pyrite	.....	.....	2.18	2.76
Water	.73	1.40	.03	.68
	99.74	101.30	100.91	101.75
Less excess CaO			.39	
			100.52	

In accordance with the older nomenclature the name ilmenite nelsonite has been given the general type of dike rock represented by the four analyses above, occurring in the Nelson County area, composed of a granular mixture of ilmenite and apatite as the dominant minerals. The norms calculated from the four analyses are given in tabular form above. The position of the rocks in the quantitative system of classification may be expressed as follows:

No.	Symbol	Name
I.	$\mathrm{V}._{\mathrm{II}}$ 5. 4(5). 2. 5.	Nelsonose (name proposed)
II.	$\mathrm{V}._{\mathrm{II}}$ 5. 4. 2(3). 5.	
III.	$\mathrm{V}._{\mathrm{II}}$ 5. 5. (2)3. 5.	
IV.	$\mathrm{V}._{\mathrm{II}}$ 5. 5. (2)3. 5.	

Rocks of this type have not been described from any other locality and no analyses are known. They form a new type among known igneous rocks and, since III and IV are considered to be the most representative of the type, the name *nelsonose* for the county in which the rock was first found is proposed as an appropriate subrang name for the rock.

The position of the rock (III and IV) in the new system may be expressed as follows:

Symbol: $\mathrm{V}._{\mathrm{II}}$ 5. virginare.
$\mathrm{V}._{\mathrm{II}}$ 5. 5. virginore.
$\mathrm{V}._{\mathrm{II}}$ 5. 5. 3. nelsonase.
$\mathrm{V}._{\mathrm{II}}$ 5. 5. 3. 5. nelsonose (subrang)

DETAILS OF OCCURRENCES.

Description of some of the typical occurrences of ilmenite nelsonite and those showing slight variation from the normal rock are given below.

About half a mile southwest of Rose Union a nelsonite dike (Spec. 107) is exposed by several cuts and may be traced by loose fragments on the surface for a distance of 400 yards in a direction S. 75° W. This dike is directly in alignment with the long, rutile-bearing dike on the property of the General Electric Company (page 176) and may represent a continuation of that ore-body. The rock is composed of about 80 per cent ilmenite with disseminated grains of apatite ranging from 0.5 to 1 mm. in diameter. Microscopically, the rock is even-granular in texture, and composed of the following minerals named in order of abundance: Ilmenite largely in excess with apatite as the essential minerals, and titanite as a minor accessory. Several small spherulites are observed formed along the contact between apatite and ilmenite, which suggest probable secondary formation. The mineral composing the spherulites could not be identified with the microscope, and it is too scarce to permit of separating from the other minerals for a chemical determination. Its birefringence is a little above that of quartz, has parallel extinction (orthorhombic), and is probably optically positive (+). The direction of slowest vibration (Z) is coincident with the long direction of the fibres.

In the bluff along the south side of Piney River, 600 yards south of the General Electric Company's mine, is a large outcrop of coarsely crystalline ilmenite (Spec. 123) from which the small amount of apatite originally present has been completely removed by solution.

A large dike of nelsonite (Specs. 40 and 41) outcrops about half a mile southeast of Jonesboro and may be traced for about 600 yards in a direction N. 13° W. The amount of ilmenite varies in different portions of the dike from 60 to perhaps 90 per cent. The apatite occurs evenly disseminated in slightly elongated grains about 1 mm. in diameter. A second dike approximately parallel to this one outcrops 300 yards to the west. A thin section of the rock (Spec. 40), under the microscope, shows a granular mixture of ilmenite and apatite, in which ilmenite greatly predominates. The apatite shows in some cases partial crystal boundaries, and is much altered at times to the earthy form osteolite. Slight alteration of ilmenite to leucoxene is observed in parts of the thin section.

About three-quarters of a mile northeast of Jonesboro a nelsonite dike (Spec. 49), traced for nearly 400 yards and having a strike nearly north and south, is exposed by five small pits. The rock is greatly altered from weathering, but appears to be a typical nelsonite with perhaps a little more apatite than is usual. In places the dike contains inclusions of fine-grained chlorite one to two inches across. Microscopic study of a thin section of the rock shows a granular mixture of ilmenite and apatite with some feldspar and biotite. All the minerals show alteration. Ilmenite is fractured and partly altered to leucoxene. Apatite contains abundant inclusions of an indeterminate character and, in places, is altered to earthy osteolite discolored a reddish-brown from liberated iron oxide. The feldspar is andesine, $Ab_{60}An_{40}$, as shown by extinctions measured on the rhombic section. There is some intergrown microcline in spindles, which are oriented parallel to the two twinning planes (001) and (010). It is noteworthy that the feldspar is identical with that in the syenite, gabbro, and gabbro-nelsonite.

Another dike (Spec. 50) outcrops about 100 yards farther east with a strike of N. 26° E., and could be traced for about 200 yards. It has been opened in two places by small surface pits. The rock is slightly finer grained than the normal nelsonite and the grains of apatite are not as well formed as in most places. Some of them contain inclusions of ilmenite. Microscopically, the rock is a fine-granular mixture of ilmenite and apatite in nearly equal proportion. Apatite in large and small irregularly rounded and angular grains is chiefly inclosed in the ilmenite, and is much altered. In some areas the ilmenite is threaded through the apatite in such fashion as to suggest an intergrowth of the two minerals. Ilmenite shows some alteration to leucoxene.

About a quarter of a mile northeast of Bryant a 50-foot shaft was sunk some years ago on a large nelsonite dike (Spec. 56) having a strike of N. 55° E. The dike is exposed by many surface cuts and may be traced for a distance of nearly 700 yards. The width is uncertain, as the pits had partly caved at the time of visit by the writers, but it is probably not less than 20 feet in some places. The rock is even-granular in texture and contains about 60 per cent of ilmenite. All exposures of the rock are badly weathered. Under the microscope a thin section of the rock shows a granular mixture of ilmenite and apatite with the former in excess. Apatite is inclosed by the ilmenite, the former sometimes displaying partial crystal outline, is partly altered to osteolite, and shows cleavage and the usual inclusions. Ilmenite is very fresh. There occurs quite a sprinkling of an indeterminate mineral having high double refraction and high index of refraction with parallel extinction, and is more or less discolored from

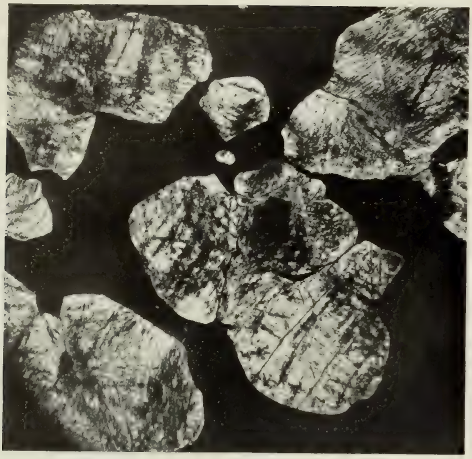


Fig. 1.—Ilmenite nelsonite from shaft 0.25 mile northeast of Bryant. Light areas apatite, showing partial alteration to the earthy form; black areas ilmenite. Single nicol. Enlarged 21 diameters. Specimen No. 56.

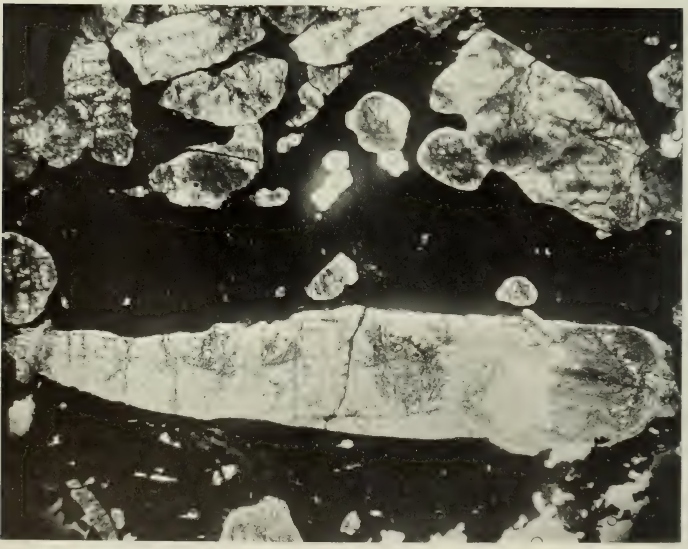


Fig. 2.—Porphyritic ilmenite nelsonite. 0.75 mile northwest of Bryant. Light areas apatite, dark areas magnetite or ilmenite partly altered to hematite. Note the long crystal (phenocryst) of apatite in lower half of figure. Single nicol. Enlarged 10 diameters. Specimen No. 61-A.

PHOTOMICROGRAPHS OF ILMENITE NELSONITE.

iron oxide stain. It occurs as irregular grains between individuals of apatite and similarly of ilmenite, and between apatite and ilmenite individuals. Plate XIII, fig. 1, is a photomicrograph of the thin section.

On the opposite side of the road, 200 to 300 yards therefrom, a number of pits were sunk in prospecting for nelsonite, but at the present time they are largely refilled and little is to be seen. On the top of nearly every ridge a little nelsonite float and traces of old pits may be found. They fall into approximate alignment in a northeast-southwest direction for a distance of more than a mile, but it is doubtful if the dike is continuous for such a distance. Float (Spec. 66) from one of the old pits 300 yards north of Bryant is composed of an even-granular mixture of ilmenite and apatite with lenticular inclusions or segregations of decomposed gray, talcose material. The lenses range up to 5 cm. in length and probably represent segregations of a silicate mineral, for some of them contain included grains of apatite. The float at most of the old pits contains more or less biotite and secondary chlorite. Under the microscope a thin section of the rock (Spec. 66) shows a fine-grained aggregate of biotite shreds largely altered to chlorite. Much ilmenite extensively altered to leucoxene is inclosed by the biotite, and many crystals of primary titanite occur.

Three dikes cross the road one mile northeast of Bryant. They are spaced about 34 yards apart, have a width of about 10 feet, and strike N. 75° W. The rock (Spec. 76) is much weathered but appears to be a normal ilmenite nelsonite. A thin section studied under the microscope shows a typical ilmenite nelsonite of normal granularity, and composed of nearly equal amounts of ilmenite and apatite. The only other constituents present are the alteration products osteolite and yellow iron oxide stain. Both ilmenite and apatite are developed in formless grains and each contains inclosures of the other mineral, indicating approximately simultaneous crystallization of the two constituents. The alteration of apatite to osteolite, a very light gray, nearly white, opaque earthy substance, is beautifully shown, with all stages in the alteration readily traceable. Many of the apatite grains are almost completely altered to osteolite.

On the northwest side of the road about 1.25 miles northeast of Bryant and near the north end of the syenite a nelsonite dike (Spec. 80) is exposed by an old cut. The dike is 15 to 20 feet or more in width and has a strike of N. 70°-80° E. It is an ilmenite nelsonite containing considerable biotite, and in portions of the dike enough biotite is present to classify the rock as biotite nelsonite. The rock probably contains some magnetite also, for it repels and attracts the magnetic needle.

In the outside gneiss 400 yards west of the last dike (Spec. 80), a large body of nelsonite is exposed by a surface cut. The strike and width could not be determined. It (Spec. 79) is a fine-grained dark gray rock composed of apatite grains 0.5 to 1 mm. in diameter, fine-granular ilmenite, and a little chlorite. The rock is slightly foliated in structure. Microscopically a thin section shows a finer grained rock in texture than normal nelsonite. It is composed of ilmenite and apatite in nearly equal amount with much nearly colorless hornblende present. The ilmenite is altered along cracks which has resulted in the liberation of much yellow iron oxide stain, incloses apatite, and in several instances is intergrown both with apatite and hornblende. The apatite is considerably altered but otherwise exhibits no unusual features. The hornblende appears to be secondary derived probably from pyroxene although no trace of the original mineral is indicated.

On the Camden farm about 1.75 miles northeast of Bryant, and in the outside gneiss half a mile or more from the syenite, a nelsonite dike 4 feet wide is reported to have been cut by a tunnel 200 yards in length. When visited in 1909 the tunnel had caved and only a few pieces of nelsonite (Spec. 81) could be found on the dump. These were composed of an even-granular mixture of apatite, ilmenite, a little magnetite, and chlorite. A small flake of graphite was identified in one piece of the rock.

Specimen 214, represented by the analysis in column I on page 109, is from a large body of nelsonite exposed in the bluffs bordering the lowlands along the west side of Tye River, one mile northwest of Roseland. A small cut was made in the outcrop to expose the dike which appears to have a nearly north-south strike. This is probabuy the widest nelsonite dike in the district, as it is 65 feet or more across. The rock is an even-granular mixture of ilmenite and apatite, partly altered from weathering.

On the opposite side of the river a large lenticular body of ilmenite nelsonite has been exploited by a series of small shafts, surface pits, and drill holes. As shown by the map of the outcrop, fig. 5, the ore-body is very irregular in outline. The rock is a typical ilmenite nelsonite and when fresh contains some pyrite that is partly secondary. The photograph of

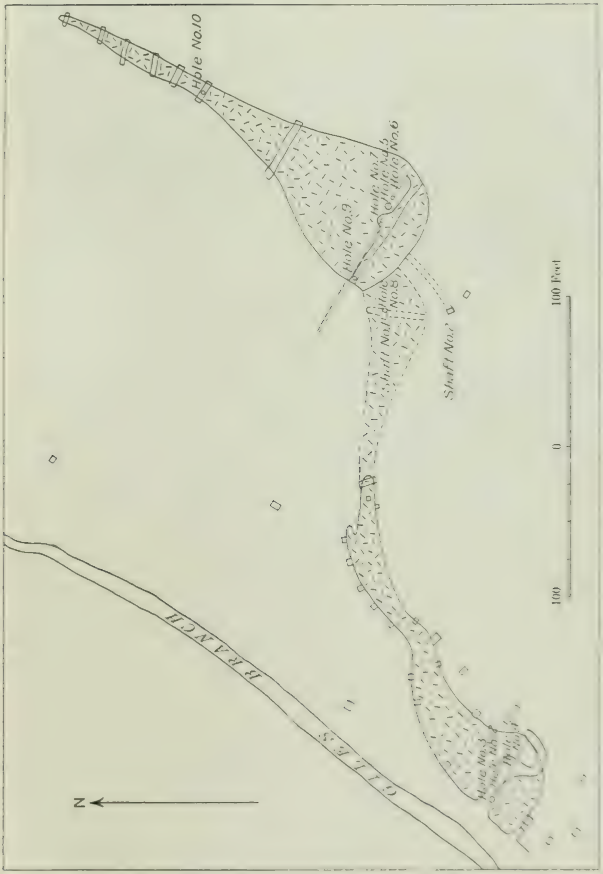


Fig. 5.—Map showing a part of the nelsonite bodies on the Giles farm 1 mile northwest of Roseland. (Adopted from map by S. W. Douglas, loaned by courtesy of W. M. Slater.)

a drill core from one of the borings showing the contact between nelsonite and syenite is reproduced as fig. 6.

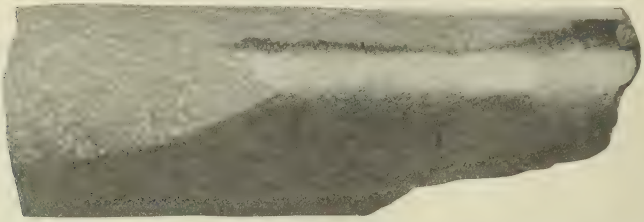
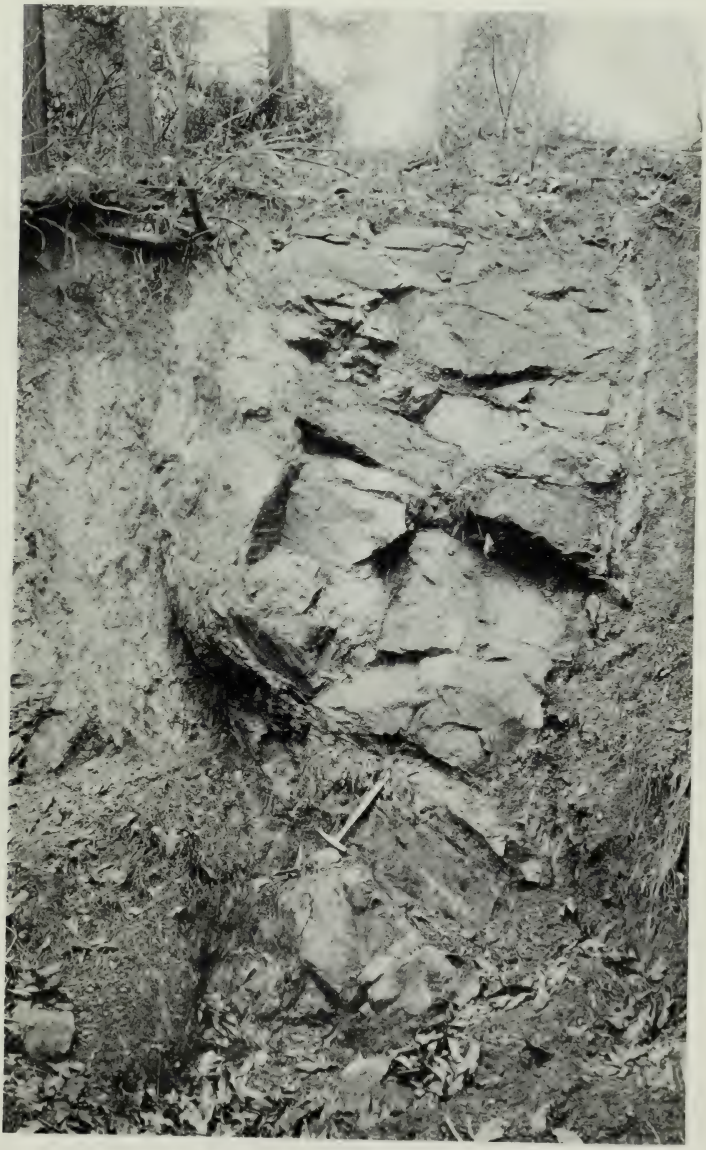


Fig. 6.—Drill core from one of the borings in nelsonite on the Giles farm 1 mile northwest of Roseland, showing contact between nelsonite and syenite. (Loaned by courtesy of W. M. Slater.)

About 300 yards to the northeast a second dike (Spec. 211) is exposed by a surface cut along the direction of strike. The character of this dike is shown in Pl. XIV, a photograph taken in the face of the cut. The nelsonite body is 8 feet wide at the surface but becomes narrower near the bottom of the opening. The upper portion is displaced several feet to the left by a small fault that crosses the dike just back of the hammer. The dike may be traced by exposures and loose surface fragments for a distance of nearly 400 yards along a direction N. 57° E. The rock appears to contain a little more apatite than the average ilmenite nelsonite, and the grains are somewhat larger in size and less regular. Some fractures in the rock are filled with manganese oxide in the form of wad. Microscopically a thin section of the rock shows the principal minerals ilmenite and apatite in the order of abundance named, together with some biotite which is considerably altered and in part may possibly be secondary. Ilmenite and apatite exhibit their usual characteristics.

A small dike of fine-grained nelsonite (Specs. 45 and 47) is exposed near Hat Creek, half a mile northeast of Jonesboro. It has a width of 2-3 feet and a strike of N. 51° E., but could be traced for a distance of only 40 feet. Portions of the rock are so fine-grained in texture that it is impossible to identify individual minerals by the unaided eye, but in other portions ilmenite and apatite may be distinguished. Under the microscope a thin section of the rock (Spec. 47) shows a fine-granular mixture of ilmenite and apatite in nearly equal proportion and greatly altered. Apatite contains inclusions of dark to black opaque substance of



Nelsonite dike cut by a small fault. Hammer indicates position of fault. Hight place 1.75 miles west of north from Roseland.

NELSONITE DIKE.

indeterminate character, and crystals of strong double refraction and high index of refraction, which resemble zircon. Some biotite occurs in such relations as to suggest secondary origin in part. Several zircon (?) crystals occur in the large biotite area of the slide. Much leucoxene is noted as an alteration product from ilmenite.

Rutile Nelsonite.

NAME AND DISTRIBUTION.

Rutile nelsonite is the name given to that facies of the rock nelsonite in which the mineral rutile enters as an important constituent. The rutile-bearing dikes show all gradations in the ratio of rutile and ilmenite, from a granular mixture composed of dominant rutile and apatite with little or no ilmenite to one (ilmenite nelsonite) composed of ilmenite and apatite with or without subordinate rutile. Gradations between these two extremes are observed in the same dike. The rock with dominant rutile and apatite in a given position in the dike may gradually pass vertically or laterally into a phase of the rock composed essentially of ilmenite and apatite.

The distribution of rutile nelsonite is entirely limited to the large syenite area, and is a much more restricted type than the normal rock, ilmenite nelsonite. Dikes of rutile nelsonite are found at several places southwest of Rose Union on the Warwick tract and Bourne farm within 1,000 yards of the syenite border, and on the Giles tract half a mile northwest of Roseland, the latter being the only known occurrence of nelsonite in the central portion of the syenite area.

MEGASCOPIC CHARACTER.

In general character, including texture, physical appearance and mode of occurrence, rutile nelsonite is closely similar to that of ilmenite nelsonite. It is a dark-colored rock of even-granular texture, the individual grains of which average about 2 cm. in diameter. It is composed essentially of rutile and apatite with ilmenite absent or only sparingly present, but by increase of ilmenite and decrease of rutile the rock passes into the normal nelsonite.

Rutile nelsonite is more variable in composition and the minerals, especially apatite, show a tendency to segregate out in the form of parallel lenses or bands giving the rock an appearance of imperfect banding. This variation does not occur suddenly but takes place as a gradation, and the size of the individual apatite grains remains uniformly the same, 1 to 2 mm. in diameter, even in the largest lenses of practically pure apatite.

At the General Electric Company's mine, near Rose's Mill on Piney River, masses of coarse rutile occur practically free from impurities other than sulphides, but they do not seem to be as numerous as the apatite segregations. By increase of apatite they grade into the even-granular nelsonite.

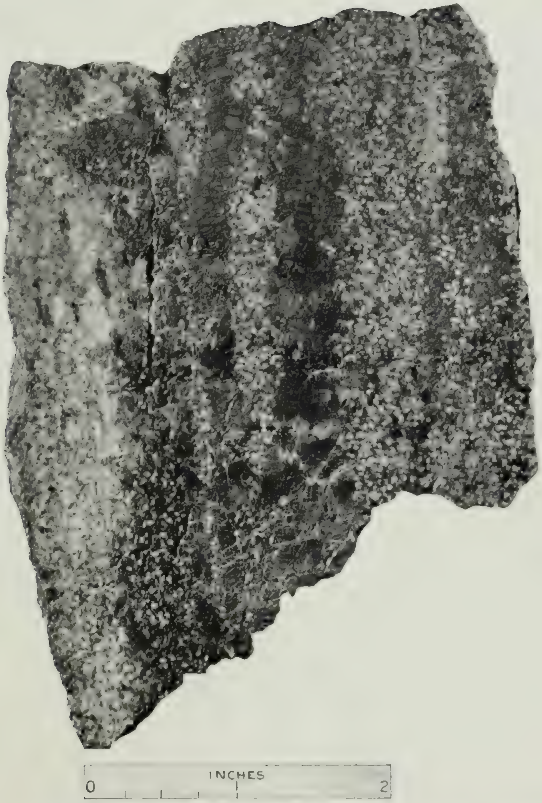
Some blue quartz of the same character as that of the syenite is present in most of the rutile nelsonite on the Warwick tract, where is opened the General Electric Company's mine. The quartz is found concentrated in largest quantity along the contact with syenite, or where there are included masses of the latter in the nelsonite. Along such contacts very small shreds of light brown biotite can usually be distinguished.

Small bodies of rutile nelsonite occur that have no definite walls but grade into the inclosing syenite, and have the appearance of segregations rather than of true dikes. This was not observed in any of the ilmenite nelsonites.

Plate XV is a polished specimen of rutile nelsonite, natural size, which exhibits imperfect banding due to partial segregation of rutile and apatite. Masses of nearly pure rutile grade into bands of nelsonite in which apatite predominates. (See Pls. XXX and XXXI.) Apatite apparently crystallized first, and in places very fine veinlets of rutile penetrate the apatite grains.

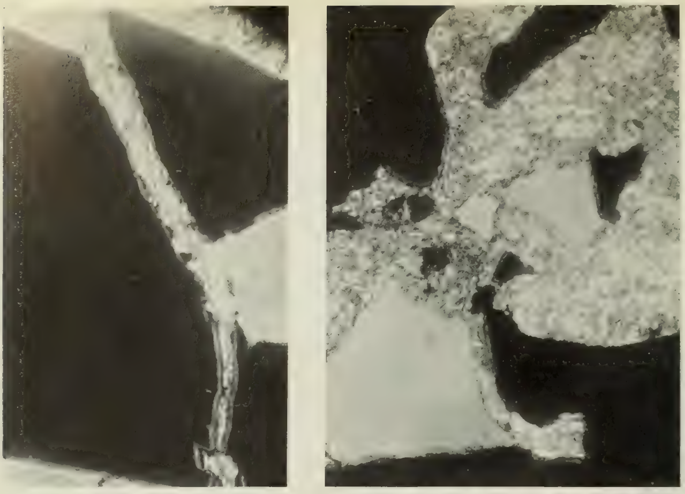
MICROSCOPIC CHARACTER.

Thin sections cut from rock specimens collected from the different dikes in the district, show an even-granular mixture of the dominant minerals rutile and apatite with variant ilmenite, which may fail entirely in some sections. Either rutile or apatite may predominate in a given thin section and in some the two minerals may be present in approximately equal amount. The accessory minerals are ilmenite, pyrite, and in several thin sections, quartz and feldspar. Leucoxene and the earthy form of apatite, osteolite, are nearly constant secondary minerals; the leucoxene being derived from rutile and from ilmenite when present, and the osteolite from apatite. When present feldspar shows partial alteration to colorless mica. The principal minerals rutile and apatite, and ilmenite when present, usually occur in formless grains, although apatite frequently manifests a tendency toward crystal outline. The relations of the minerals are such as to suggest simultaneous crystallization, the individuals mutually interfering with each other at the time of formation, resulting in irregular interlocking boundaries rather than outward crystal form.



Polished specimen of rutile nelsonite, showing parallel (banded) segregations of rutile and apatite, General Electric Company's mine, Nelson County. The dark bands are rutile; the light ones are apatite. (Collected by Frank L. Hess. Photographed by U. S. Geol. Survey.)

BANDED RUTILE NELSONITE.



Figs. 1 and 2.—Rutile (dark areas) in syenite. American Rutile Company's quarries at Roseland, showing alteration rims of leucoxene. Nicols crossed. Enlarged 30 diameters. Specimens Nos. 43-AW and 43-BW. See also Pl. IX.

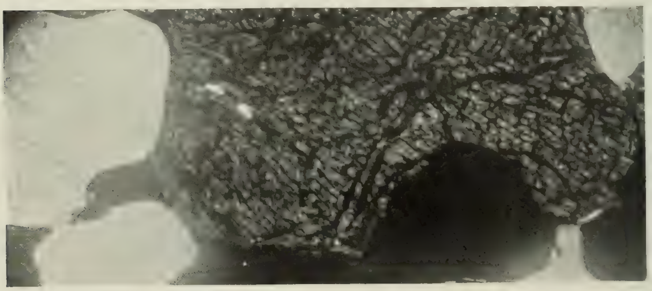


Fig. 3.—Rutile nelsonite, General Electric Company's mine. Light areas apatite; medium dark gray area rutile; black areas ilmenite. Single nicol. Enlarged 30 diameters.

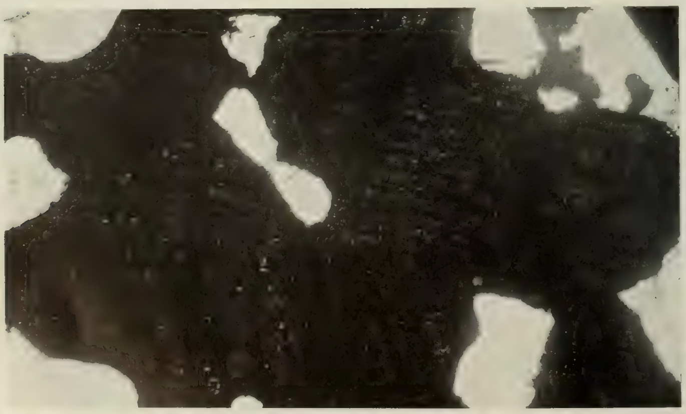


Fig. 4.—Rutile nelsonite, General Electric Company's mine. Same as fig. 3. Single nicol. Enlarged 30 diameters.

PHOTOMICROGRAPHS OF SYENITE RUTILE AND RUTILE NELSONITE.

Rutile, in anhedral form, is dark yellowish to reddish-brown, often displaying distinct but variable pleochroism, usually shows both cleavage and twinning, and is remarkably free from inclusions. The absorption is $E > O$. Rutile is partly altered peripherally and along fractures to leucoxene. Small granules of rutile are occasionally noted inclosed in the apatite. (See Pl. XVI, figs. 3 and 4.)

A specimen of rutile, isolated and cleansed, from rutile nelsonite at the General Electric Company's mine yielded the following results on analysis:

Analysis of rutile from rutile nelsonite, General Electric Company's mine.
(WM. M. THORNTON, JR., *Analyst.*)

	Per cent.
TiO_2	98.80
FeO	1.68
SiO_2	0.26
V_2O_3	0.20
Cr_2O_3	0.07
SnO_2	None
Cb_2O_5	None
Ta_2O_5	None
	101.01
Specific gravity	4.21

The chief interest which attaches to the composition of the nelsonite rutile, shown in the analysis above, as well as that of the syenite rutile (page 194), is the presence of vanadium and chromium in very small but determinable amounts. A determination of the melting point of the rutile represented by the analysis above, made by the Bureau of Standards, gave 1700° C.

Apatite exhibits the usual optical properties. When fresh and free from inclusions it is fairly clear and of a faint bluish-white color, without visible pleochroism. It usually occurs in somewhat rounded or oval-shaped grains, with frequent indications of crystal boundaries noted. In many of the grains traces of cleavage are shown. Unlike rutile the apatite is usually characterized by an abundance and variety of inclusions oftentimes of an indeterminate nature. These are partly dark, dustlike particles and partly crystallites, some of which have been identified as rutile, ilmenite, and apatite. The inclusions not infrequently show orientation along a cleavage direction. In many grains the apatite substance is partly obscured by irregular areas and patches of an opaque earthy product of dark gray color which has been identified as osteolite. Alteration is likewise noticeable to some degree along cleavage directions and fractures.

The composition of the apatite is shown in a chemical analysis of the mineral from one of the segregated bands in the nelsonite at the General Electric Company's mine on page 108.

Quartz and feldspar of the same character as that of the inclosing syenite were noted in several thin sections. The quartz shows optical disturbance and contains abundant rutile needles. Feldspar is partly altered to colorless mica. Pyrite is formed between individual grains of rutile and apatite and to some extent in fractures. The relations suggest a secondary origin for at least a part of the pyrite.

CHEMICAL COMPOSITION AND CLASSIFICATION.

The chemical composition of rutile nelsonite is shown in the two analyses below of specimens collected from the General Electric Company's mine near Rose's Mill, on Piney River, and the Giles tract near Roseland, in Nelson County.

Analyses of rutile nelsonite from Nelson County, Virginia.

	I	II
TiO_2	69.67	65.90
Fe_2O_3	2.87	3.65
FeO	5.04	7.95
MgO	0.15	0.25
CaO	12.16	11.13
P_2O_5	9.41	8.14
H_2O-	0.09	0.21
H_2O+	0.11	0.35
SiO_2	0.67	0.95
MnO	.....	0.26
CO_2	.....	Trace
S	0.34	1.61
F	0.70	0.34
Cl	Trace	None
	101.21	100.74
Excess O	0.39	0.54
	100.82	100.20
Specific gravity	3.76	......

I. Rutile nelsonite taken from ore-dump of adit level, General Electric Co.'s mine, Nelson County, Virginia.

II. Rutile nelsonite taken from dike on Giles tract near Roseland, Nelson County, Virginia.

Specimen (215) represented by the analysis in column I was collected from the dump of the General Electric Company's mine. The rock is a very dark, even-granular mixture of essentially rutile and apatite through which is distributed a goodly amount of pyrite. Microscopically it is composed of rutile and apatite with some ilmenite and titanite and much pyrite. The usual decomposition products are noted. All the minerals show their usual characteristics as described on page 118.

The analysis in column II is of a specimen (29) collected from a rutile nelsonite dike 4.5 feet thick exposed by a prospect pit on the Giles[a] tract near Roseland. The strike is S. 56° W., and the dip about 65° towards the southeast. Another opening was made about 100 feet south on what appears to be a second dike. The float indicates a strike of approximately S. 17° W. The rock is composed of rutile and apatite grains averaging 1 mm. in diameter, and blue quartz. The blue quartz is probably primary, but a small veinlet of white quartz 1 to 7 mm. wide was noted cutting the nelsonite. The weathered rock is dark copper, bronze in color and pitted by the removal of apatite.

Microscopically the rock is composed of rutile and apatite as the principal minerals, together with accessory ilmenite, feldspar, and quartz. Secondary minerals are leucoxene derived from rutile and ilmenite, colorless mica in small shreds and scales from feldspar, and osteolite from apatite. The quartz contains abundant rutile needles and shows optical disturbance and partial granulation.

Norms of rutile nelsonite corresponding to analyses on page 120.

	I	II
Quartz	0.42	.....
Hypersthene	0.40	.....
Diopside	.....	1.79
Hematite	2.88	3.68
Ilmenite	9.73	13.22
Rutile	64.56	58.96
Apatite	22.18	19.15
Pyrite	0.62	3.00
Water	0.20	0.56
	100.99	100.36

[a] A polished section of a specimen collected by Frank L. Hess from a rutile nelsonite body on the Giles tract, is very interesting in showing (1) a vein of colorless, transparent, glassy and milky quartz, 1.25 inches wide, on one side of (2) massive rutile inclosing an area, 3 inches long by 0.50 to 0.75 inch across, of typical rutile nelsonite. The line of contact between the quartz and rutile is perfectly sharp, probably indicating that the quartz is later than the rutile. The rutile is interlaced by innumerable tiny threadlike fractures, along which alteration to a white to gray substance, probably leucoxene, has progressed. Larger areas and stringers of the same substance are abundant. A fair sprinkling of pyrite, which is probably secondary, occurs with the rutile.

The rock represented by the above analyses and the norms calculated therefrom is a new type. It is a variety of the general type nelsonite, in which rutile is a dominant mineral, and in conformity with the older scheme of classification the name *rutile nelsonite* has been given it. The position of the rock in the quantitative system of classification may be expressed as follows:

No.	Symbol	Name
I.	$V._{II}$ 5. 5. 4. 5.	Virginose
II.	$V._{II}$ 5. 5. (1)2. 5.	

The position in the new system represented by these symbols is unoccupied, and for No. I which is regarded as the most representative the subrang name *virginose* is proposed. Its position in the new system is fixed as follows:

Symbol: $V._{II}$ 5. virginare.
$V._{II}$ 5. 5. virginore.
$V._{II}$ 5. 5. 4. virginase.
$V._{II}$ 5. 5. 4. 5. virginose.

No. II has a slightly different position in the scheme from No. I, but, since it occupies in part a border position and is essentially the same rock, it is believed a new name is unwarranted.

OTHER LOCALITIES.

On the Bourne farm, 600 yards northeast of the General Electric Company's shaft and approximately in line with the strike of the longer dike on the latter property, two trenches have been cut exposing several narrow stringers of rutile nelsonite (Spec. 114). These stringers range from less than an inch to two feet in width. They are even-granular in texture, and have the appearance of segregations rather than of intrusives, as they grade into the inclosing syenite and do not exhibit sharply defined contacts. The syenite is composed of feldspar and a little blue quartz with occasional grains of rutile which, near the nelsonite, are arranged in broken lines parallel to the stringers. A little ilmenite nelsonite float is found on the surface intermingled with pieces of rutile nelsonite. Thin sections cut from specimens of the rutile nelsonite show under the microscope the same minerals with similar characters and relations as the rock occurring to the southwest on the General Electric Company's property, described on pages 184-191.

An old pit, 600 yards southwest of Rose Union, exposes a dike of ilmenite nelsonite (Spec. 106) which can be traced by float in a direction S. 60° W. Along this line of strike pieces of rutile nelsonite were found in several places. One specimen showed irregular lenses or bands of rutile 1 to 2 cm. wide similar to the occurrences in the General Electric Company's mine described on page 184.

Magnetite and Biotite Nelsonites.

NAME AND DISTRIBUTION.

The names magnetite nelsonite and biotite nelsonite are given to those varieties of nelsonite which show special richness in these two minerals. They grade into each other and for this reason are treated together under the same head. In most occurrences the two minerals, magnetite and biotite, are intimately associated, but in unequal and variable amounts; when magnetite is dominant biotite may vary from an abundant to a very minor accessory, and a similar variation in magnetite may take place when biotite is the dominant mineral.

Magnetite and biotite nelsonites do not occur within the syenite area, but are found in the outside gneiss both in the Lovingston district and in the Hat Creek section of the Roseland district. In the Hat Creek section they are found at many places along the slopes of the range forming the northwest side of the valley, and extend from Brent's Gap to a point about one mile southwest of Jonesboro. In the Lovingston district they occur at many places within half a mile to three miles from the town of Lovingston.

MEGASCOPIC CHARACTER.

The chief difference in magnetite and biotite nelsonites from normal (ilmenite) nelsonite is composition; color, texture, and mode of occurrence being essentially the same. They are dark, even-granular rocks, varying from fine- to medium-grained in texture and massive to schistose in structure. They are composed essentially of magnetite, biotite, and apatite, with either magnetite or biotite the dominant mineral. The biotite nelsonite in places occurs as a border facies along the walls of magnetite nelsonite dikes. A second probable extreme variation in the nelsonites is that of a rock composed of almost pure granular apatite with magnetite or ilmenite and biotite as microscopic accessories, as indicated in an occurrence noted near the southern end of the line of nelsonite outcrops, 1.75 miles southwest of Lovingston, and described in detail on page 128.

MICROSCOPIC CHARACTER.

Microscopic thin sections of the rocks disclose an equigranular fine-to medium-grained texture. Their mineralogy, in common with all the nelsonites of the region, is simple, being characterized by only a few minerals. Magnetite with probably some ilmenite, biotite, and apatite are the chief primary constituents, with in one section a few crystals of titanite which are comparable in size to the other minerals. Either magnetite or biotite may be the predominant constituent, and in practically all thin sections the two minerals are present, but in very unequal and variable quantity. The secondary minerals include chlorite, the commonest and most abundant, derived from biotite; osteolite derived from apatite which is a frequent alteration product; leucoxene occurs only sparingly.

Biotite is of the ordinary brown variety, possessing strong absorption and good cleavage, and may be present either as an abundant or as a minor accessory mineral. It occurs as aggregates of small shreds, sometimes as larger platy flakes, and in some thin sections is partly inclosed in the magnetite.

Apatite is a constant principal constituent of each variety of the rock. It exhibits the usual optical characters previously described; shows a marked tendency toward crystal form, occurring as subhedral to euhedral forms and as rounded grains. Abundant dark inclusions chiefly dustlike particles sometimes larger in size but of an indeterminate character are incorporated in the apatite substance. Apatite is frequently inclosed in the magnetite.

Magnetite probably accompanied by some ilmenite occurs both as a principal and as a subordinate constituent. It presents no noteworthy characters except that in some thin sections much of the apatite and some of the biotite are inclosed in it, indicating that its period of formation was in part at least subsequent to that of the other two minerals, especially apatite. Further confirmation of this is shown in the lack usually of crystal boundaries of the magnetite.

CHEMICAL COMPOSITION AND CLASSIFICATION.

The chemical composition of magnetite and biotite nelsonites is shown in the two analyses given below. The specimens yielding the results in the subjoined table were collected two miles southwest (I) and half a mile west (II) of Lovingston, Nelson County.

Analyses of magnetite and biotite nelsonites from Nelson County.
(WM. M. THORNTON, JR., *Analyst.*)

	I	II
TiO_2	15.78	16.48
Fe_2O_3	31.45	43.34
FeO	20.20	18.61
MgO	0.64	0.66
CaO	12.73	5.48
P_2O_5	9.40	4.98
H_2O-	0.20	0.51
H_2O+	0.97	1.62
F	0.23	0.26
Cl	Trace	Trace
SiO_2	1.24	4.24
Al_2O_3	n. d.	3.45
Na_2O	0.10	0.15
K_2O	0.34	0.45
MnO	0.23	0.12
CO_2	.....	Trace
S	.....	Trace
	99.42	100.24
Specific gravity	4.214	......

I. Magnetite nelsonite, Dillard farm 2 miles southwest of Lovingston.
II. Biotite nelsonite, half a mile west of Lovingston.

The analysis in column I was made on material collected from a large dike, exposed by an open cut on the Dillard farm, 2 miles southwest of Lovingston. The dike is almost 8 feet wide and dips toward the east at an angle of 45° to 55°, the strike being nearly north and south. It may be traced by the float for a distance of 100 yards or more along its course.

In the centre of the dike, the rock (Spec. 160) is largely composed of titaniferous magnetite with disseminated grains of apatite which range up to 0.5 mm. in diameter. A few shreds of biotite mostly altered to chlorite are present but they are of minor importance. Passing toward the contacts of the dike biotite increases and magnetite decreases while the percentage of apatite remains nearly uniform. Along the contacts there is a zone 1 to 2 inches wide composed almost exclusively of biotite. The dike rock is so strongly magnetic that a hammer held within the cut close to the outcrop becomes magnetized and is able to attract and hold small fragments of the rock. When the hammer is raised above the outcrop out of the lines of magnetic force it loses its magnetism and drops the fragments of rock.

The surrounding rock, mica-schist, is completely weathered to clay so that a little kaolinized feldspar and some small grains of blue quartz are the only constituents that can be observed. Like ilmenite and rutile nelsonites, the magnetite nelsonite on weathering gives the typical pitted surface by the removal of apatite.

Under the microscope, a thin section of the rock (Spec. 160) showed the principal minerals to be magnetite and apatite in nearly equal amounts with much biotite partly altered to chlorite. Magnetite is reasonably fresh and shows no alteration to leucoxene. Apatite exhibits cleavage in some individuals and contains abundant inclusions chiefly of dark opaque dust-like particles. It is partly altered to osteolite in places and some discoloration from liberated iron oxide occurs. Biotite is abundant as small aggregates of shreds and larger platy forms. It is brown in color, has strong absorption and good cleavage, and much of it is altered to chlorite with the separation of granules of black iron oxide. Plate XVII, fig. 1, is a microphotograph of the thin section.

Analysis II represents material collected from a large outcrop of biotite nelsonite (Spec. 171) located just over the crest of the ridge half a mile west of Lovingston. The dike is about 8 feet wide and can be traced for a distance of 400 feet along the strike which is N. 40° E. It is a dark, fine-grained rock, schistose in structure, and composed of magnetite or ilmenite, apatite, and biotite, the latter being altered largely to chlorite.

Microscopically the rock is fine-grained in texture and composed chiefly of magnetite or ilmenite, less apatite and biotite, with several large crystals of titanite. Apatite shows some tendency toward crystal form, is inclosed by the magnetite, and is quite fresh, exhibiting its usual optical characters. Biotite, mostly brown, sometimes green in color, with good cleavage and strong absorption, occupies distinct areas at times as aggregates of shreds, but much of it is inclosed by the magnetite.

The norms calculated from the analyses on page 125 are:

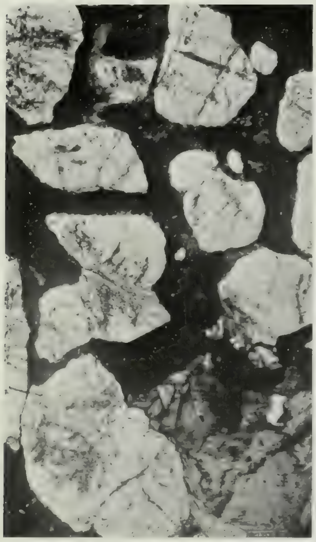


Fig. 1.—Magnetite nelsonite, Dillard farm, 2 miles southwest of Lovingston. Light areas apatite, dark areas magnetite chiefly. Single nicol. Enlarged 30 diameters. Specimen No. 160.

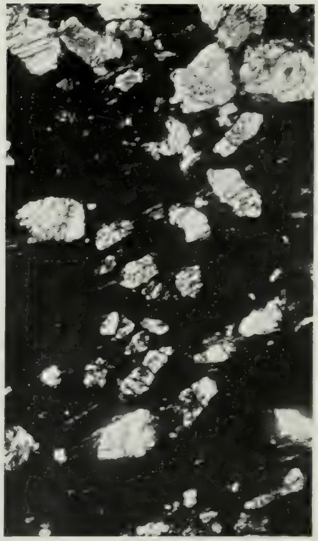


Fig. 2.—Fine-grained ilmenite nelsonite 0.75 mile northwest of fig. 1. Light areas apatite, dark areas ilmenite. Single nicol. Enlarged 30 diameters. Specimen No. 163.

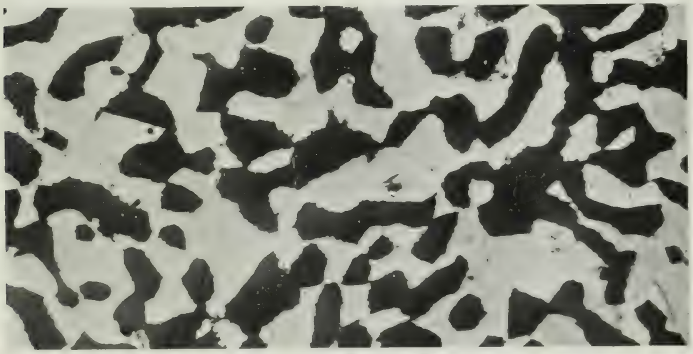


Fig. 3.—Intergrowth of ilmenite and quartz, 1.5 miles southwest of Claypool. Light areas quartz, dark areas ilmenite. Single nicol. Enlarged 30 diameters. Specimen No. 99.

PHOTOMICROGRAPHS OF NELSONITE AND ILMENITE-QUARTZ INTERGROWTH.

Norms corresponding to analyses of magnetite and biotite nelsonites on page 125.

	I	II
Quartz	.....	0.42
Orthoclase	.....	2.78
Albite	.....	1.57
Corundum	.....	2.65
Leucite	1.31	.....
Nephelite	0.57	.....
Hypersthene	.....	1.60
Olivine	0.70	.....
Ilmenite	30.10	31.31
Magnetite	19.72	12.06
Hematite	23.04	35.20
Apatite	22.18	9.74
Water	1.17	2.13
	98.79	99.46

The position of the first one of these rocks (I) in the "Quantitative System" may be expressed as follows:

No.	Symbol	Name
I.	$V._{II}$ 5. (2)3. (2)3. (4–5).	None

The position of the rock represented by analysis II is not figured out since either CaO is too low or P_2O_5 is too high, which makes a difference in classification.

These represent new and extreme types of ultrabasic igneous rocks. They are the first recorded representatives, but no name is suggested for the one figured out (I) since it occupies a border position in the classificatory scheme. An accurate analysis of entirely fresh material may remove the rock from a border position and place it within the proper classificatory limits. Should this prove true the subrang name *lovingstonose* is suggested as an appropriate one.

OTHER OCCURRENCES.

A similar dike to that described above on the Dillard farm occurs 1.5 miles north of Lovingston (Spec. 190). There are no outcrops at this point but the float indicates a nearly north and south strike. Pieces of nelsonite may be found in which either magnetite or biotite predominates.

Microscopically a thin section shows the rock to be a fine-granular mixture of magnetite, ilmenite, apatite, and biotite in the order of abundance named. Biotite occurs in small shreds and large platy forms of green and brown color, exhibiting the usual pleochroism and cleavage, and is partly altered to chlorite. Magnetite or ilmenite and apatite show their usual characters.

Biotite nelsonite is found at a number of places along the ridge on the west side of the Lovingston valley. These occurrences fall approximately into alignment and extend for a distance of 3 miles in a direction N. 35° E.

Near the southern end of the line of nelsonite outcrops, 1.75 miles southwest of Lovingston, there is a 12-foot shaft on the southwest side of which a vertical dike of nelsonite (Spec. 164) not exceeding 1 foot in width is exposed, but it pinches before reaching the opposite side of the shaft. The strike appears to be approximately N. 28° E. The rock is composed of dominant apatite, biotite, and a little ilmenite, and is much decomposed. There is a large open cut a few feet southwest of the shaft from which a carload of apatite is reported to have been mined and shipped. A few pieces left on the dump are composed of almost pure white apatite, fine-grained and close-textured, with scattered dark gray blotches probably due to minute inclusions of biotite or ilmenite. The small dike exposed in the shaft is probably the continuation of this ore-body which must have been more or less lenticular in shape.

Microscopically a thin section showed chiefly light-colored apatite in euhedral and anhedral forms, with the mineral usually exhibiting a strong tendency toward crystal outline, both basal and prismatic sections being frequent. Two directions of cleavage are sometimes noted and inclusions of minute dustlike particles and larger dark granules of an indeterminate character are frequent. The apatite is not entirely fresh but is partly altered to the earthy form, osteolite. Brown pleochroic biotite partly altered to chlorite and ilmenite or titaniferous magnetite altering to leucoxene occur as lesser constituents. Areas of a fine mosaic of epidote and some zoisite, minute granules of black oxide of iron, and some yellow-brown hydrous iron oxide frequently formed along the boundaries of the minerals, complete the list of secondary minerals.

About 50 yards southwest of the open cut a dike of biotite nelsonite (Spec. 163) is exposed in a small pit. The dike is 3 feet wide and has a strike N. 40° E. It is a dark gray schistose rock, composed of biotite, apatite, and magnetite or ilmenite. A part of the apatite occurs in long, lathlike crystals ranging up to 2 cm. in length. The biotite is largely altered to chlorite and some hematite derived either from magnetite or ilmenite is present.

Microscopic study of a thin section reveals a rock of fine-grained texture, composed of the principal minerals ilmenite or magnetite, biotite, and apatite in the order named. Biotite, next in quantity to ilmenite or magnetite, is deep brown in color and pleochroic, and occurs in aggregates of shreds, partly inclosed by the iron-bearing mineral. Apatite is considerably altered to a bright yellowish substance, possibly iron oxide, which is especially noticeable along the lines of fracture. Plate XVII, fig. 2, is a photomicrograph of the thin section.

A dike of magnetite nelsonite (Spec. 27) outcrops on the Stratton farm, three-quarters of a mile southeast of Massie's Mill. While not well exposed the body is probably 2 or 3 feet wide and has a strike of N. 50° E. When fresh the rock is black and has metallic lustre, but on weathering it becomes rusty brown to black in color due to the production of limonite. It contains much titanium but is strongly magnetic. Apatite is evenly distributed in small, elongated grains but forms a very small percentage of the total rock mass. Microscopically the rock is fine-grained in texture composed of the principal minerals magnetite, apatite, and biotite, together with the usual alteration products. Apatite in euhedral and anhedral forms is developed as inclosures in both magnetite and biotite.

On the slope of the mountain three-quarters of a mile northwest of Bryant is exposed a rock (Specs. 61-A and 61-B) composed of hematite and apatite. The hematite, fine granular and black in color, is secondary after magnetite. The rock contains very little titanium. Apatite is largely segregated in the central portion of the dike developed as phenocrysts ranging up to 2 cm. in length and 4 or 5 mm. in diameter that frequently show well-formed, hexagonal cross-sections. A few small grains of the mineral are disseminated through the outer portions of the rock mass. A thin section of 61-A studied under the microscope shows the following minerals: Apatite, hematite, magnetite or ilmenite, and biotite. Apatite is the most abundant mineral and is developed in large, elongated crystals containing inclusions and showing alterations. (Pl. XIII, fig. 2.) 61-B differs in mineral composition from 61-A. It is composed of hematite, biotite, and quartz, no apatite or ilmenite being identified. Hematite is secondary after magnetite. Quartz exhibits pronounced optical disturbance and characteristic peripheral granulation. An occasional hairlike inclusion of rutile is noted in the quartz. Although the rock is very fine-grained in texture blue quartz is plainly visible in the hand specimen.

Near the headwaters of Hard Bargain Branch, one of the upper forks of Hat Creek, 3.5 miles northeast of Bryant, a nelsonite body (Spec. 83) outcrops that is composed of magnetite, ilmenite, apatite, and some chlorite probably derived from the alteration of biotite. A similar rock is exposed near Brents Gap on the other side of the ridge, one mile to the east. Other dikes of the same character are reported to occur at several places along the mountain slopes in this vicinity. Microscopically the rock is fine-grained in texture and composed of ilmenite, apatite, and biotite, the first two being present in about equal proportion, as the principal minerals, together with some accessory primary titanite. Biotite in brown- and green-colored shreds showing good cleavage, strong absorption, and containing inclusions, is plentiful. Ilmenite and apatite are considerably altered to the usual products.

In the outside gneiss about one mile north of Jonesboro a small pit exposes a dike of nelsonite which can be traced along the strike N. 5° W. for a distance of 500 yards. The rock is fine-grained in texture, of dark gray color, and composed of chlorite, apatite, magnetite, and probably ilmenite. Under the microscope a thin section of the rock shows magnetite or ilmenite or both, biotite, apatite, and accessory titanite, together with the secondary minerals chlorite, leucoxene, and osteolite as alteration products derived from the three principal minerals biotite, ilmenite, and apatite.

AN EXCEPTIONAL FACIES.

In several places along the southern portion of the ridge on the west side of the Lovingston valley, large masses of pure apatite occur associated with biotite schists, and as these masses seem to be closely related genetically to the biotite nelsonites they are described below.

About three-quarters of a mile southwest along the ridge there is an old shaft 30 feet deep and several prospect pits, but only completely weathered schist was observed on the shaft dump. A piece of weathered float picked up near one of the pits is composed almost entirely of biotite with a little apatite and possibly some ilmenite. A similar specimen from another cut contains a little hornblende and shows an included mass of pure apatite about 5 cm. across. Passing southwest there are many prospect pits and open cuts within the next 400 yards, and in some of them large masses of apatite were encountered, closely associated with a fine-grained pegmatite and a peculiar biotite schist. (See figs. 7, 8, and 9.)

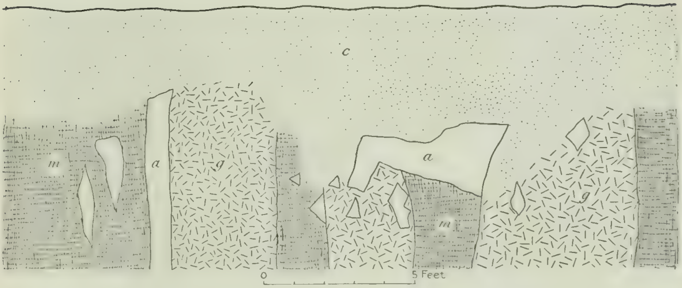


Fig. 7.—Section in open cut on the Dillard farm, 2 miles southwest of Lovingston, showing geologic relations of the rocks. (*a*) Apatite, (*c*) residual decay, (*g*) pegmatite, (*m*) mica schist.

The geological relations of these rocks (Specs. 169 and 170) to each other are complicated, and the intense metamorphism to which they have been subjected, together with the depth to which decomposition has penetrated, makes it exceedingly difficult to decipher. The peculiar appearance of the schist is well shown in one of the small shafts, and in figs. 8 and 9 sections of the shaft are given together with diagrammatic sketches of the southwest and southeast sides. A photograph of the biotite schist

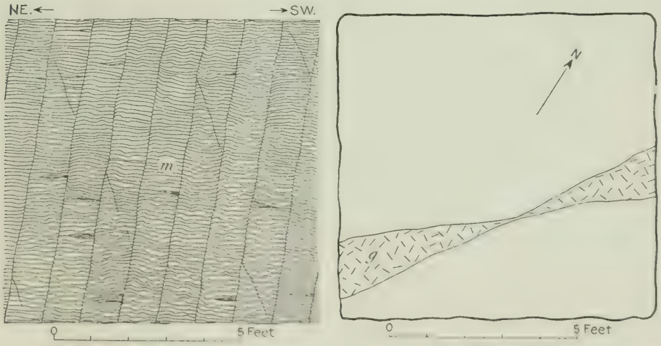


Fig. 8.—Vertical and horizontal sections in shaft on the Dillard farm, 2 miles southwest of Lovingston. (*g*) Pegmatite, (*m*) mica schist. (See fig. 9.)

on the southeast side of the shaft is reproduced in Pl. XVIII. The direction of schistosity is nearly vertical and approximately parallel to the side of the shaft where the photograph was taken. The schist is divided by horizontal partings into wavelike layers about half an inch thick, which at a little distance have the appearance of bedding planes. These lines of parting may be traced in places across both the pegmatite and the apatite masses, but are not as distinctly marked as in the schist, and the rock is also cut by nearly vertical joints. It is dark brown in color, and is so badly weathered that it readily crumbles to pieces (altered mica folia) between the fingers. It is composed mostly of altered biotite, and, as shown under the microscope, a few angular grains of quartz. A chemical test showed the presence of much phosphoric acid.

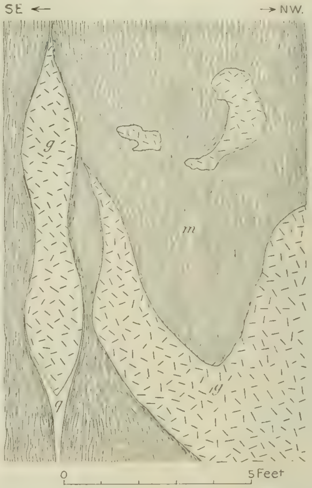
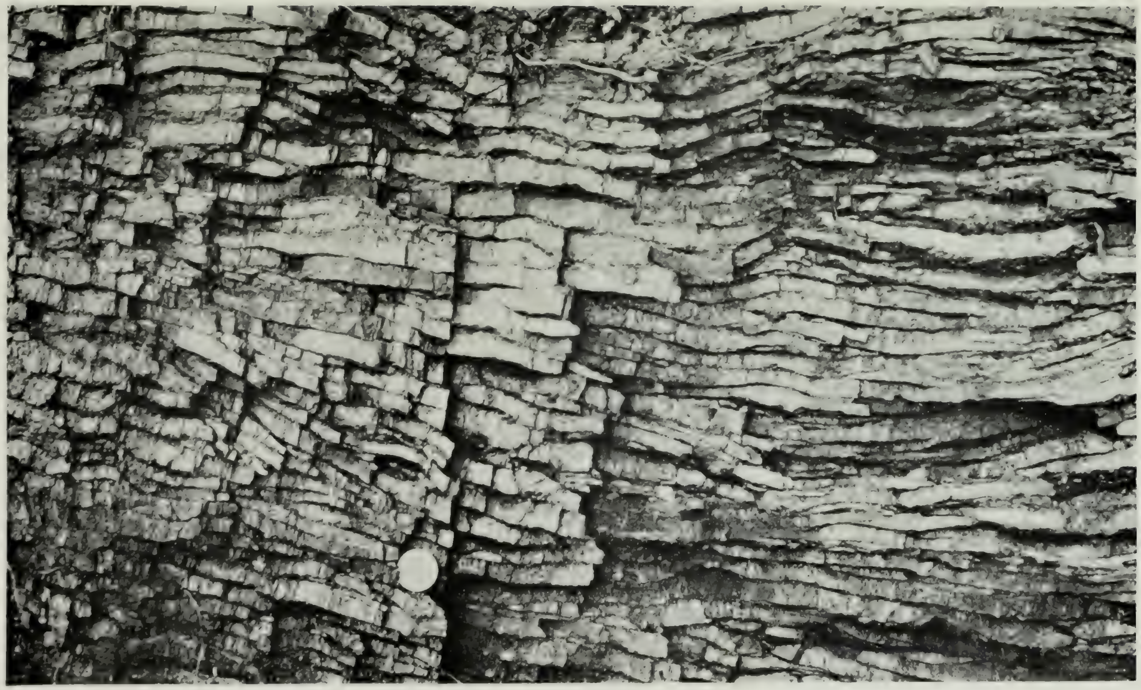


Fig. 9.—Vertical section in shaft on the Dillard farm, 2 miles southwest of Lovingston. (*g*) Pegmatite, (*m*) mica schist, (*q*) quartz.

The pegmatite (Spec. 165) occurs as lenses and irregular masses cutting the schist, and as large bodies that appear to be included in the schist. Megascopically it is a medium, coarse granitic rock composed for the most part of feldspar, quartz, and a little biotite, together with some muscovite which is probably secondary.

Apatite in irregular masses is found both in the pegmatite and in the biotite schist, and along the contact between the two. It is white to semitransparent when fresh, and occurs as a compact, even-grained mass, comparatively free from other minerals except occasionally a little fine biotite or ilmenite. In one piece a lenticular veinlet of quartz about 1 cm. wide was noted.

Because of the altered condition of the rocks and the imperfect exposures it is not possible to draw definite conclusions regarding the origin of these deposits, but many of the known facts suggest that the apatite masses may have been formed as segregations in an igneous rock which has since been altered to the biotite schist. The principal facts favoring this explanation are:



Mica schist on Dillard farm, 2 miles southwest of Lovingston, showing peculiar horizontal parting. The half dollar piece in lower part of figure indicates the scale.

MICA SCHIST.

(1) The known occurrence of this biotite schist and the apatite masses which accompany it are in alignment with the series of biotite nelsonites that outcrop along a line 3 miles in length, and they are not found elsewhere.

(2) The close physical resemblance between the biotite schist and the biotite nelsonites, in which apatite and ilmenite or magnetite occur as minor constituents.

(3) The presence of parallel cracks in many specimens of biotite nelsonites somewhat similar to the false bedding in the schist.

(4) The occurrence of small quantities of biotite and ilmenite in the apatite masses, and the presence of considerable phosphoric acid in the biotite schist.

(5) The small masses of segregated or included apatite that are found in biotite nelsonite otherwise containing only small amounts of apatite in disseminated grains.

(6) These ore-bodies are accompanied by pegmatite masses and nelsonite dikes, the latter having been found only in syenite areas and in the vicinity of pegmatite dikes. This statement is true of the nelsonite dikes found in the Roanoke area as well as those in the Roseland and Lovingston districts.

Hornblende Nelsonite.

NAME AND LITHOLOGIC CHARACTER.

The name hornblende nelsonite is given to that variety of nelsonite showing special richness in hornblende. Rocks of this type occur at several widely separated localities in the Lovingston district, and in the Roseland district about one mile west of Rose's Mill. Entirely fresh specimens of the rock could not be obtained. Secondary chlorite derived from hornblende is a prominent constituent of the rocks and in some specimens it is the principal mineral.

In the freshest specimens the rock is dark in color, by far the most prominent constituent being compact, cleavable hornblende more or less altered to chlorite. Other more altered specimens show a rock of medium, dark blue-gray to greenish-gray color. The other important mineral constituents, apatite and ilmenite, form very small grains frequently distributed through the hornblende and its alteration product, chlorite, in poikilitic fashion. Occasional irregular, fine-granular areas are visible in some specimens in which the apatite and ilmenite are more prominent than elsewhere. The rock is medium to coarse granular in texture and massive to slightly foliated in structure.

MICROSCOPIC CHARACTER.

Under the microscope thin sections of the rocks show a micropoikilitic texture, the large, irregular areas of hornblende and its alteration product, chlorite, being more or less crowded with apatite and ilmenite. The chief constituent is pale to deep blue-green hornblende in grains and irregular platy forms, sometimes fibrous, having pronounced pleochroism in the deeper colored individuals, and usually showing well-developed cleavage in one direction. The hornblende is partly altered to chlorite accompanied at times by the separation of granules of black oxide of iron. It seems not improbable that much of the hornblende was derived from pyroxene, although no trace of this mineral was observed except in one thin section which showed several small cores or eyes of hypersthene surrounded by hornblende.

The next most abundant constituents are apatite and ilmenite, the proportions of which are subject to wide variation, and always greatly less in amount than hornblende. Ilmenite is mostly anhedral and in some thin sections is partly altered to leucoxene. Much of the apatite in some sections is in euhedral and subhedral crystals, partially altered at times to the earthy form osteolite. Both ilmenite and apatite are more frequent as inclosures in the hornblende imparting poikilitic texture. In one thin section a part of the apatite was observed inclosed by the ilmenite, indicating that apatite was the first mineral to form.

Biotite in small amount is occasionally noted associated with hornblende. A thin section of the rock from the Roseland district shows much biotite and chlorite but no hornblende. It is brown to green in color, exhibiting the usual absorption and cleavage in fresh folia, but partly altered to chlorite.

Titanite, quartz, and probably zircon (?) were noted as occasional accessory minerals in several thin sections, but all of these were not observed in the same thin section.

CHEMICAL COMPOSITION AND CLASSIFICATION.

Chemical analyses of this rock from the Roseland and Lovingston districts are as follows:

Analyses of hornblende nelsonite, Nelson County, Virginia.
(WM. M. THORNTON, JR., *Analyst.*)

	I	II
SiO_2	20.02	33.89
Al_2O_3	2.64	.94
Fe_2O_3	11.75	6.85
FeO	16.98	22.73
MgO	5.93	6.85
CaO	10.27	9.68
Na_2O	.23	.37
K_2O	.39	.34
H_2O-	.71	.32
H_2O+	2.47	1.66
TiO_2	20.73	12.97
P_2O_5	7.34	3.29
MnO	.23	.31
Cl	.02	.01
F	.31	.02
CO_2	Trace	Trace
Total	100.02	100.23

I. Hornblende (biotite-chlorite) nelsonite, 1 mile west of Rose's Mill, Nelson County, Virginia.
II. Hornblende nelsonite, 3 miles north of Lovingston, Nelson County, Virginia.

The norms calculated from these analyses are as follows:

Norms of hornblende nelsonite corresponding to analyses on page 135.

	I	II
Quartz	7.50	7.86
Orthoclase	2.22	1.67
Albite	1.57	3.14
Corundum	1.84	.....
Diopside	.....	21.92
Hypersthene	14.80	20.97
Hematite	11.68	.....
Magnetite	.....	9.98
Ilmenite	36.33	24.78
Titanite	3.53	.....
Rutile	.16	.....
Apatite	16.80	7.73
Water	3.18	1.98
Total	99.61	100.03

Separate descriptions of the rocks represented by the two analyses above follow:

Specimen No. I (126) was collected from large pieces of loose rock, about one mile west of Rose's Mill, distributed along the direction of strike of several nearby nelsonite dikes. The rock is medium granular in texture, of green color, and schistose in structure. It is composed principally of medium green chlorite and scattered smaller grains of apatite and ilmenite.

Under the microscope a thin section of the rock shows it to be much altered. It is composed of biotite, ilmenite, and apatite as the principal minerals, together with accessory quartz, and the secondary minerals chlorite and leucoxene. Biotite is brown to green in color, has strong absorption and good cleavage in the fresh folia, but much of it is altered chiefly to chlorite. Hornblende was not identified. Chlorite, the most abundant mineral, may or may not have been derived entirely from biotite. Ilmenite contains fractures and is considerably altered to leucoxene. Apatite likewise shows alteration to the earthy form osteolite. An occasional grain of quartz is observed.

Specimen No. II (192) was taken from the Shipman farm, 3 miles north of Lovingston, where many loose pieces of hornblende nelsonite are found scattered over the slope of the mountain. No rock could be found in place but the float was fairly fresh. The rock is composed chiefly of dark green hornblende, partly in large, cleavable individuals 3 to 4 mm. across, and partly in small grains, through which are distributed small grains of ilmenite and apatite in poikilitic fashion.

Microscopically a thin section of the rock shows it to be composed chiefly of large, irregular, platy, green, pleochroic hornblende having good cleavage developed in one direction. It is micropoikiltic in texture from enclosures of the other minerals, and is partly altered with, in some cases, the separation of grains of black oxide of iron. It is not improbable that the hornblende is secondary although no trace of an original mineral from which it may have been derived was observed in the thin section. The next most abundant constituents are apatite and ilmenite. Much of the apatite in euhedral and subhedral crystals is enclosed in the hornblende and to some extent in the ilmenite. Titanite is present in small quantity. Plate XIX, fig. 2, is a photomicrograph of the thin section.

Under the old nomenclature these rocks would be classed as hornblende nelsonite, the prefix hornblende denoting special richness in that mineral. In the new quantitative system of classification, the norms as

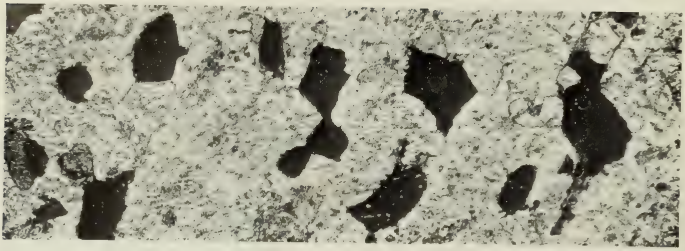


Fig. 1.—Hornblende nelsonite from Bradshaw farm, 0.5 mile southeast of Lovingston. Shows hornblende, ilmenite, and apatite. Single nicol. Enlarged 30 diameters. Specimen No. 177.

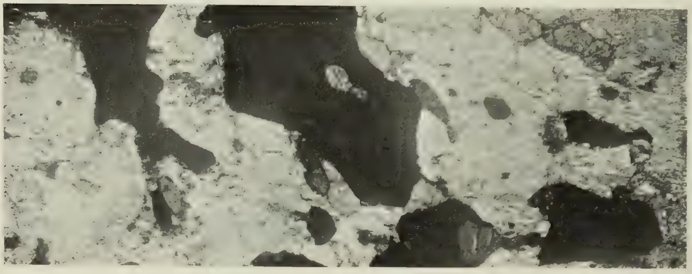


Fig. 2.—Hornblende nelsonite from Shipman farm, 3 miles north of Lovingston. Shows hornblende, ilmenite, and apatite. Nicols crossed. Enlarged 30 diameters. Specimen No. 192.

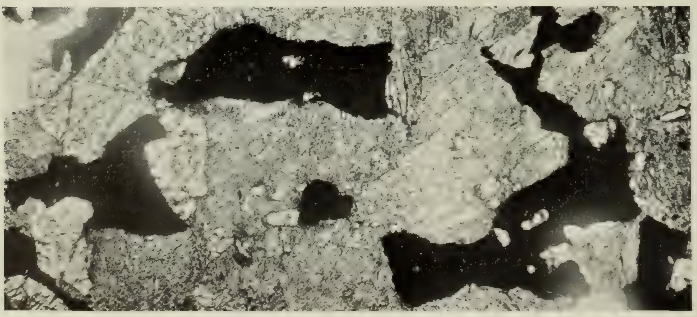


Fig. 3.—Hornblende nelsonite 1.75 miles northwest of Lovingston. Shows altered hornblende, ilmenite, and apatite. Nicols crossed. Enlarged 30 diameters. Specimen No. 186.

PHOTOMICROGRAPHS OF HORNBLENDE NELSONITE.

shown above, place the rocks near the border position between classes IV and V, but they are classed as of IV (dofemane). These rocks are the first recorded representatives of a new type. Their position in the quantitative system of classification is expressed as follows:

I. Symbol, IV (near V). 2. 4. 4. 1. 2(3). 3(4) almost 4.
II. Symbol, IV–V. 1(2). 3. 1. 1. 4. (3)4. Classed as in IV.

No name is proposed for these rocks at this time since they occupy a border position between classes IV and V of the "Quantitative System," but chiefly because of the lack of fresh material for chemical analysis.

OTHER OCCURRENCES.

Two other occurrences of hornblende nelsonite in the Lovingston district are described below.

About 1.25 miles west from the Shipman farm there is a similar occurrence of hornblende nelsonite (Spec. 186). The float was traced for a short distance in a direction N. 70° W., but no rock was found in place. The rock is dark greenish-gray, and massive granular but uneven texture, composed chiefly of large platy, poikilitic hornblende and in places areas of an even-granular mixture of dominant apatite and ilmenite. Float found in this vicinity indicates that the country rock is biotite gneiss with a few dikes of granite and diabase.

Microscopically a thin section of the rock shows it to be composed essentially of pale green, fibrous hornblende, slightly pleochroic; and under the single nicol it appears homogeneous and massive. The hornblende has been derived from hypersthene as there are some scattered eyes or cores of the characteristic unaltered pyroxene in the hornblende substance. Hornblende encloses ilmenite and apatite, the latter probably slightly in excess, having the usual characteristics. Alteration to hornblende is accompanied by the separation of grains of black oxide of iron through its substance. Several pieces of primary titanite are observed. Plate XIX, fig. 3, is a photomicrograph of the thin section.

On the Bradshaw farm, 0.5 mile southeast of Lovingston, a small prospect pit was sunk on a dike of hornblende nelsonite (Spec. 177) several years ago. At present the pit is partly filled, but pieces of rock found on the dump show the character of the dike. It is a dark green, coarsely crystalline rock, composed of compact, cleavable hornblende crystals 3 to 4 mm. in diameter, and minute grains of apatite and ilmenite.

Microscopic study of a thin section of the rock shows the chief constituent to be green hornblende in grains and platy prismatic forms having strong pleochroism. Some biotite is associated with the hornblende, and apatite partly altered and ilmenite are sprinkled quite freely through the slide. Anhedral quartz, and crystals of a mineral having strong refraction and double refraction, probably zircon, occur. Plate XIX, fig. 1, is a photomicrograph of the thin section.

Gabbro-Nelsonite.

NAME AND DISTRIBUTION.

The name gabbro-nelsonite was proposed by the writers[a] for a type of holocrystalline igneous rock, occurring as dikes and having mineralogical composition intermediate between normal gabbro and nelsonite proper.

Gabbro-nelsonite is much more limited in occurrence than that of either gabbro or nelsonite. It has been observed and studied at many places within the syenite area, especially near the eastern border, and has been observed in the outside gneiss near the head of Davis Creek. A description of each occurrence is detailed in the pages which follow below. Most of the occurrences of gabbro-nelsonite are remarkably uniform in appearance and composition. In places the rock shows a partial gneissic structure, the constituent minerals being drawn out so as to give an appearance of imperfect banding. Other rocks are found within the district which are intermediate in mineral composition between gabbro and gabbro-nelsonite. They resemble more closely the gabbro in appearance but contain excessive quantities of the ore minerals, ilmenite and apatite.

MEGASCOPIC CHARACTER.

Normally gabbro-nelsonite is a holocrystalline, porphyritic rock of dark color, consisting of lenticular eyes of feldspar (plagioclase), 1 to 2 cm. in diameter, embedded in a dark, medium-fine, even-granular groundmass of pyroxene, ilmenite, and apatite. Even-granular texture has been noted in only one or two occurrences of the rock. Other variations, chiefly mineralogical, exist which are described separately below. In the typical gabbro-nelsonite, the lenticular eyes of feldspar, which give to the rock porphyritic texture, frequently appear not as a single large feldspar individual but as an aggregate of small, formless grains, which may and probably do represent granulation or crushing of an original large feldspar phenocryst by dynamic metamorphism.

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[a] Watson, Thomas L., and Taber, Stephen, The Virginia Rutile Deposits, Bull. No. 430, U. S. Geol. Survey, 1910, p. 59.

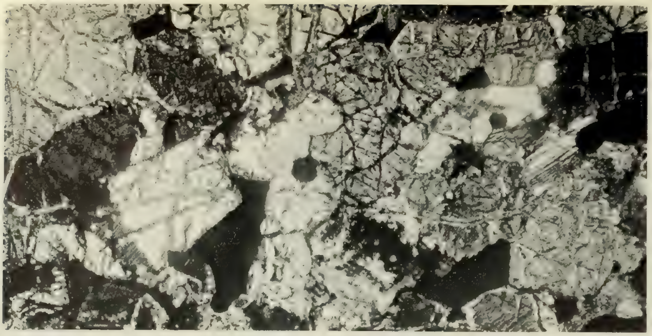

Fig. 1.—Gabbro from exposure in road in front of Mr. Adams' house at Roseland. Shows the principal minerals pyroxene (hypersthene), plagioclase (andesine), ilmenite, and occasional rutile. Nicols crossed. Enlarged 30 diameters. Specimen No. 19.

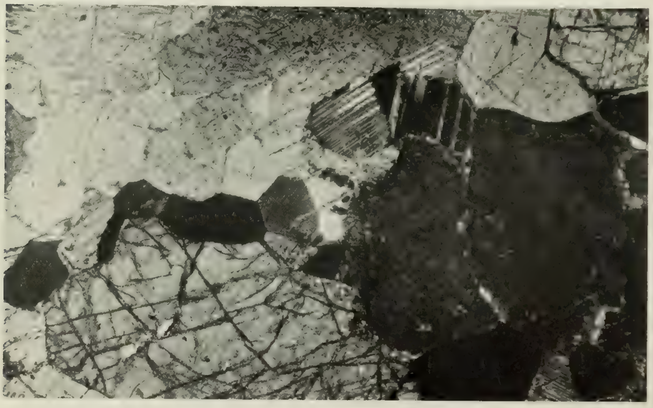

Fig. 2.—Gabbro-nelsonite from M. C. Massie's place, 1.75 miles southwest of Bryant. Shows pyroxene (hypersthene), plagioclase (andesine, partly intergrown with spindles of orthoclase), ilmenite, and apatite. Nicols crossed. Enlarged 30 diameters. Specimen No. 49.

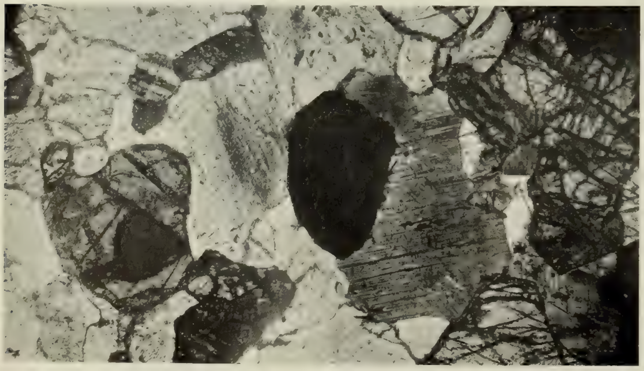

Fig. 3.—Gabbro-nelsonite 1 mile east of Rose Union. Shows pyroxene (hypersthene), plagioclase (andesine, partly intergrown with orthoclase), ilmenite, and apatite. Nicols crossed. Enlarged 30 diameters. Specimen No. 135-A.

PHOTOMICROGRAPHS OF GABBRO AND GABBRO-NELSONITE.

Mineralogically the typical rock is composed of silicate and ore minerals in unequal amounts, the former predominating. The dark ferromagnesian minerals, hypersthene and secondary hornblende, variant feldspar (chiefly plagioclase with some orthoclase), and occasional quartz, are the silicate minerals. Apatite, ilmenite, and magnetite are the principal ore minerals.

MICROSCOPIC CHARACTER.

Under the microscope the rock is found to consist of a holocrystalline granitoid mixture of silicate and ore minerals in unequal proportion. Porphyritic texture is less apparent in some thin sections than in the hand specimens. The essential silicate minerals, named in order of their abundance, are an orthorhombic pyroxene (hypersthene) and an intermediate plagioclase of andesine composition. The ore minerals are ilmenite and apatite, occasionally approximating nearly equal proportions but usually one is in excess of the other. Besides these sporadic grains of quartz, biotite, titanite, and pyrite have been observed. In one thin section an occasional grain of microcline was identified. The secondary minerals include hornblende, chlorite, and leucoxene.

Pyroxene is the most abundant constituent, and it seems to be hypersthene occurring as ill-defined prismoids and anhedral crystals. Pleochroism may be weak or strong corresponding usually in the deeper colored forms to the absorption formula X = yellowish-brown, Y = reddish-brown, and Z = greenish. It sometimes contains inclosures of apatite and shows various stages of alteration to a confused fibrous greenish aggregate of probably hornblende. The pyroxene is optically negative (—).

Feldspar is quantitatively the next silicate mineral of importance. It is a plagioclase of intermediate composition corresponding to andesine of the composition $Ab_{65}An_{35}$ to $Ab_{60}An_{40}$, usually exhibits characteristic multiple twinning, and does not show crystal boundaries. It sometimes shows intergrowths of microcline (orthoclase) spindles similar to the dominant feldspar observed in the syenite and in the gabbro. Extinction on rhombic sections averaged about 20.5°. Micropoikilitic texture is sometimes observed but usually is poorly defined. Occasionally the lamellæ of a plagioclase individual are broken by fractures. Inclusions of apatite occur but are not abundant. Plagioclase (andesine) is subject to considerable variation in amount and in one or two thin sections it is only sparingly present. (See Pls. XX and XXI.)

The ore minerals, ilmenite and apatite, are always present in considerable amount, and are more plentiful than feldspar, standing quantitatively next to pyroxene. Both are developed as individual crystal grains of smaller size than either of the essential silicate minerals. Apatite is chiefly developed in crystals showing tendency towards idiomorphic outline, is reasonably fresh, is sometimes partially fractured, and in part may be inclosed by either pyroxene or ilmenite, indicating its earlier crystallization from the magma. Ilmenite is partly altered peripherally to leucoxene.

The several accessory minerals are very sparingly present and do not present any unusual features.

CHEMICAL COMPOSITION AND CLASSIFICATION.

The only sample of gabbro-nelsonite analyzed during the course of this investigation was collected from a dike of the typical rock exposed on the west side of the Arrington road, one mile south of Roseland. The analysis follows:

Analysis of gabbro-nelsonite, Nelson County, Virginia.

SiO_2	33.83
Al_2O_3	5.19
Fe_2O_3	11.38
FeO	15.08
MgO	8.57
CaO	8.22
Na_2O	1.28
K_2O	0.50
H_2O-	0.45
H_2O+	0.75
P_2O_5	4.84
TiO_2	10.00
Cl	0.04
F	0.55
S.	0.25
MnO	0.26
CO_2	Trace
	101.39
Excess O	0.30
	101.09

The rock yielding this analysis is porphyritic in texture, with lens-shaped areas of light-colored feldspar (plagioclase) about 1 cm. in diameter distributed irregularly through a very dark, medium-fine, even-granular ground-mass of pyroxene, ilmenite, and apatite. A little pyrite and pyrrhotite are visible to the naked eye.

Under the microscope a thin section of the rock shows the principal minerals to be hypersthene, feldspar chiefly plagioclase (andesine corresponding to the composition $Ab_{65}An_{35}$) with very subordinate orthoclase, ilmenite, apatite, and occasional grains of quartz and pyrite. Hypersthene is altered partly to hornblende with the separation of black granules of iron oxide. It occurs mostly in anhedral crystals of irregular shapes, somewhat rounded at times, and has weak pleochroism. Ilmenite and apatite, especially the latter, manifest a tendency toward idiomorphic outline and are more plentiful than feldspar. The chief feldspar is andesine of about the composition $Ab_{65}An_{35}$ formed in subhedral and anhedral crystals which show characteristic albite twinning. Maximum extinction on sections cut normal to the albite lamellæ is 15°. Several pieces of andesine were noted containing spindle-like intergrowths of microcline or orthoclase extending nearly across the host. Plate XXI, fig. 1, shows a photomicrograph of the thin section.

The norm corresponding to the analysis above is as follows:

Norm of gabbro-nelsonite corresponding to the analysis on page 140.

Quartz	7.38
Orthoclase	2.78
Albite	11.00
Anorthite	6.95
Hypersthene	22.55
Diopside	1.51
Magnetite	16.47
Ilmenite	19.15
Apatite	11.42
Pyrite	0.42
	99.63
Water	1.20
Excess Cl, F	0.15
	100.98

The rock is a new one and is the first recorded representative of the rang and subrang. *Roselandase* and *roselandose* are suggested as appropriate rang and subrang names. The position of the rock in the quantitative system may be expressed as follows:

Symbol: IV.$_{\text{II}}$ 3. 1. 2. roselandase.
IV.$_{\text{II.}}$ 3. 1. 2. 3. roselandose.

Bergenose, an ilmenite norite from Storgang, Soggendal, Norway, is probably the closest known representative to roselandose, yet the two rocks show wide differences in chemical composition. For comparison with roselandose the analysis and norm of bergenose are given below.

Analysis and norm of bergenose (ilmenite norite) from Norway.[a]

SiO_2	31.59	Orthoclase	1.1
Al_2O_3	8.54	Albite	8.4
Fe_2O_3	2.36	Anorthite	11.1
FeO	24.52	Corundum	2.7
MgO	10.70	Hypersthene	34.6
CaO	2.25	Olivine	3.8
Na_2O	1.03	Magnetite	3.5
K_2O	0.15	Ilmenite	35.1
H_2O	n. d.		
TiO_2	18.49		
P_2O_5	0.02		
	99.65		

[a] Washington, H. S., Prof. Paper 14, U. S. Geol. Survey, 1903, pp. 364-365.

According to Washington, the position of bergenose in the quantitative system may be expressed as follows:

Symbol: IV.$_{I.}$ 3. 1. 1. 3. bergenose.

It will be observed that both rocks, roselandose and bergenose, are dofamanes (class IV), while roselandose falls into subclass II and bergenose into subclass I. Both are magnesiferrous rocks.

The essential characters of gabbro-nelsonite may be summarized briefly as follows: (a) Porphyritic texture, the even-granular texture having been observed in only one case. Light-colored feldspar (plagioclase) is the porphyritically developed mineral and is distributed irregularly through a very dark, even-granular ground-mass of pyroxene and ore minerals, chiefly ilmenite and apatite. (b) Mineralogically, the rock is composed of silicate and ore minerals in unequal amounts, the former in excess. The chief silicate minerals are hypersthene and plagioclase feldspar of the composition of andesine, the former always predominating, and the ratio between the two variable. Minor orthoclase and some secondary hornblende are usually present. The ore minerals are ilmenite and apatite which occur in large but varying proportions. Comparing the composition of bergenose with that of roselandose (pages 140 and 142), it will be observed that bergenose is rich in ilmenite but, unlike roselandose, contains scarcely more than a trace of apatite. It is noteworthy that plagioclase (andesine) of similar composition is likewise characteristic of the syenite and gabbro masses of the Virginia region. (c) Chemically, the rock is characterized by low silica, alumina, and alkalies; high iron, magnesia, and lime; and by unusual richness in titanium and phosphorus.

DETAILS OF OCCURRENCES.

Near the headwaters of Davis Creek several pits and tunnels have been opened in prospecting for apatite, but the openings were caved when visited by the writers. A specimen (85) of gabbro-nelsonite was found on one of the dumps. It is a dark brown rock consisting of feldspar phenocrysts 4 to 5 mm. in diameter embedded in a fine-grained mixture of pyroxene, ilmenite, apatite, and a little chlorite. Under the microscope the rock appears as a holocrystalline granular mixture of silicate and ore minerals, the former in largest amount. The silicate minerals are pyroxene (orthorhombic and monoclinic forms), feldspar (chiefly plagioclase of andesine composition with some orthoclase and microcline), and an occasional shred of biotite. The ore minerals are ilmenite and apatite in nearly equal amount. Pyroxene is the most abundant mineral. Micropoikilitic texture is developed in some of the larger plagioclase individuals, and occasionally the feldspar shows fractured lamellæ. Apatite and ilmenite, especially the former, show marked tendency to idiomorphic outline. Apatite is frequently inclosed by the pyroxene, and ilmenite is partly altered to leucoxene. Sporadic grains of primary titanite occur.

One mile east of Rose Union are many pieces of gabbro-nelsonite float (Specs. 135-A, 135-B, and 136) which vary considerably in appearance and composition. Specimen 135-A is a fine-grained rock showing gneissic structure, the feldspars of which are drawn out into narrow parallel lines. The principal feldspar is andesine ($Ab_{64}An_{36}$) containing a little intergrown microcline. Extinction in rhombic sections gives 15° and 18°. In addition to the intergrown microcline there are inclusions of quartz grains (rarely oriented) and apatite. Ilmenite, pyroxene, and apatite occur in small grains. Specimen 135-B is a dark gray even-grained rock composed largely of pyroxene with lesser amounts of ilmenite, feldspar, and apatite. This is one of the few gabbro-nelsonites that do not show porphyritic texture. Specimen 136 was found in the same vicinity. It is a fine-grained, dark gray rock composed chiefly of pyroxene, ilmenite, and apatite. Feldspar could not be identified.

Under the microscope a thin section of specimen 135-A shows the principal minerals to be hypersthene, feldspar (dominantly intermediate plagioclase near andesine and occasional orthoclase), ilmenite, apatite, and a few grains of quartz. The feldspar contains inclusions, and shows slight development of micropoikilitic texture. Ilmenite is partly altered peripherally to leucoxene. Apatite is fairly fresh and is crossed by fractures.

Microscopically specimen 135-B has the same mineral composition as 135-A, except that it contains less feldspar. Specimen 136 differs chiefly, under the microscope, from specimens 135-A and 135-B in the absence of feldspar. Its constituent minerals are hypersthene, apatite, and ilmenite, together with the usual alteration products derived from each. In each of the specimens hypersthene shows pronounced pleochroism: X = yellowish-brown, Y = reddish-brown, Z = greenish. A photomicrograph of thin section 135-A is shown in Pl. XX, fig. 3.

The hypersthene in thin section No. 136 is altered to a matted aggregate of colorless scales of talc with some black opaque iron ore along the cracks. The talc scales have a moderately low index of refraction and a strong birefringence. They show cleavage parallel to their length; their elongation is optically positive (+); they have a small axial angle and are optically negative (—). A little hornblende (uralite) occurs. Nearly all stages of alteration of hypersthene to talc and hornblende (uralite) are shown, from slight rims of talc and uralite to chiefly all talc and uralite inclosing nucleal remnants of hypersthene. Apatite is partly inclosed both by ilmenite and by hypersthene. A photomicrograph of the thin section is shown in Pl. XXVIII, fig. 3.

Much gabbro-nelsonite float (Spec. 52) is found scattered over the surface about 600 yards southwest of Bryant. The feldspar lenses are about 0.5 cm. in diameter and some of the feldspars show fine multiple twinning. The loose fragments of gabbro-nelsonite which litter the surface show typical pitted surfaces characteristic of nelsonites in general when long exposed to weathering. In the bluff about 150 yards to the northeast the rock (Spec. 53) occurs in place, but it has more the appearance of imperfect banding. Microscopically, thin sections of the rock show the minerals to be hypersthene, feldspar (plagioclase-andesine with occasional orthoclase), ilmenite, apatite, and several small anhedra of quartz. Hypersthene displays the usual color and pleochroism, and shows some alteration along cracks to probable bastite. The principal feldspar is andesine of the composition $Ab_{60}An_{40}$, some of which contains long, narrow bodies of intergrown microcline arranged occasionally in two sets crossing at different angles; and as irregularly rounded inclosures regularly arranged. Extinctions measured on rhombic sections gave 20°, 21°, and 21.5°. Ilmenite is partly altered peripherally to leucoxene. The apatite shows some fractures but otherwise is usually fairly fresh. Some hydrous iron oxide stain, derived from the iron-bearing minerals, occurs. Plate XXI, fig. 2, is a photomicrograph of thin section of specimen 52.

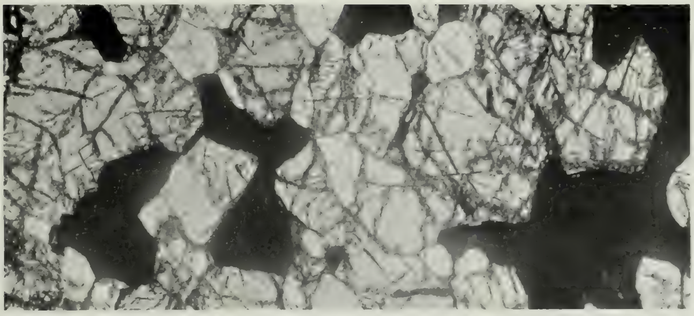

Fig. 1.—Gabbro-nelsonite on Arrington-Roseland road, 1 mile south of Roseland. Shows pyroxene (hypersthene), apatite, and ilmenite. Single nicol. Enlarged 30 diameters. Specimen No. 212.

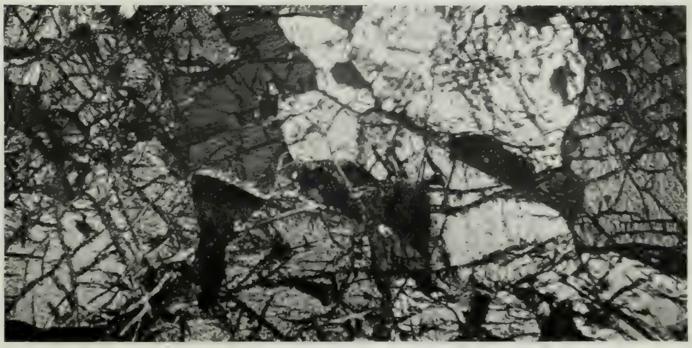

Fig. 2.—Gabbro-nelsonite three-eighths of a mile southwest of Bryant. Shows pyroxene (hypersthene), apatite, ilmenite, and plagioclase feldspar (andesine intergrown with orthoclase). Nicols crossed. Enlarged 30 diameters. Specimen No. 52.

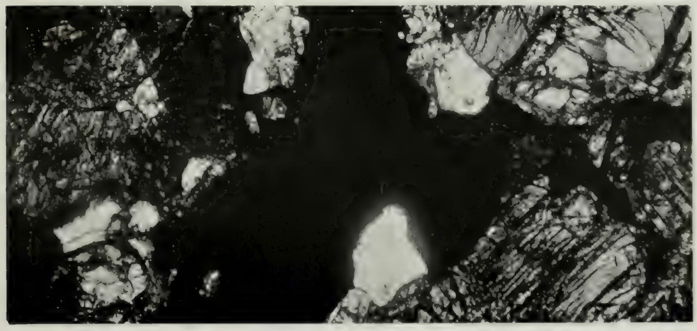

Fig. 3.—Gabbro-nelsonite on county road, 1.75 miles south of Bryant, Nelson County. Shows the same minerals as figs. 1 and 2. Nicols crossed. Enlarged 30 diameters. Specimen No. 219.

PHOTOMICROGRAPHS OF GABBRO-NELSONITE.

On the north side of the county road, 1.75 miles south of Bryant, is an outcrop of gabbro-nelsonite (Spec. 219). Microscopically the rock is closely similar to the gabbro-nelsonite occurring one mile south of Roseland, an analysis and description of which are given on pages 140-141, except that the feldspar lenses (phenocrysts) are slightly larger. The principal minerals are pyroxene (hypersthene), andesine intergrown with microcline in spindle-shaped bodies, ilmenite, and apatite. The usual minor accessory and secondary minerals are present. A photomicrograph of the thin section of this rock is given in Pl. XXI, fig. 3.

An exposure of gabbro (Spec. 220) described on page 98, containing an unusual amount of ilmenite, is exposed near by, and it is probable that the two (gabbro and gabbro-nelsonite) are facies of the same rock mass.

Just west of the county road, 1.25 miles south of Bryant, abundant loose pieces of typical gabbro-nelsonite (Specs. 89 and 90) showing characteristic pitted weathering litter the surface. In the same vicinity a similar rock is found which contains lenses of blue quartz ranging up to 3 or 4 cm. in length and 1 cm. in width embedded in an even-granular mixture of pyroxene, ilmenite, and apatite. Feldspar could not be identified in the hand specimen but the rock probably represents a phase of the gabbro-nelsonite and may belong to the same rock mass. A thin section under the microscope shows the chief ferromagnesian silicate mineral (pyroxene) to be greatly altered and of doubtful identification. Some biotite and hornblende, apatite, ilmenite, and quartz complete the list of minerals. Quartz carries hairlike inclusions of rutile, and shows wavy extinction and granulation. Ilmenite and apatite display their usual characters.

Chemical Composition of the Nelsonites.

In the accompanying table are assembled, for convenience, eight analyses of the several varieties (except hornblende- and gabbro-nelsonite) of nelsonite, arranged in the order of increasing TiO_2. The molecular ratios of the oxides are given below the percentage figures. The analyses will give a fair idea of the composition of the rocks, more especially the range in the important constituents, TiO_2, Fe_2O_3, FeO, CaO, and P_2O_5. The variations of these and of several of the important lesser constituents are best shown by comparing their molecular proportions graphically in the diagram, fig. 10, which is constructed from the analyses in table, page 147, by plotting the molecular proportions of the oxides as ordinates, taking those of titania as abscissas.

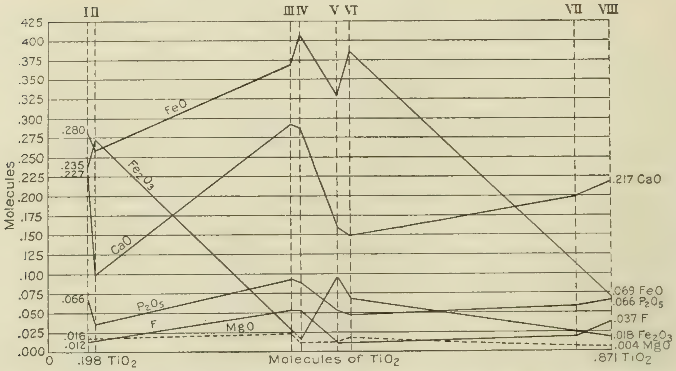

Fig. 10.—Diagram showing variation in the molecular constituents of eight nelsonites from Nelson County, Virginia.

Detailed study of the diagram shows irregularity in the variations of the principal oxides, especially FeO and Fe_2O_3. The lines representing the molecular proportions of these two oxides are antagonistic, except in the right half of the diagram both decrease but not to the same extent. Fe_2O_3 shows a general tendency to decrease with increasing TiO_2 but it is marked by great irregularity. This irregularity in FeO and Fe_2O_3 when compared with TiO_2 accords with the variable proportions of the minerals rutile, ilmenite, and magnetite present in the rocks. Of these minerals, those rocks represented on the left of the table contain magnetite and ilmenite, while those on the right contain chiefly rutile with minor ilmenite.

There is closer correspondence, however, between the lines representing the molecular proportions of CaO, P_2O_5, and F in the mineral apatite, but are antagonistic to those of FeO and Fe_2O_3, which emphasizes irregularity in the ratio of the principal minerals composing the rocks, apatite to the dark iron and titanium-bearing minerals, magnetite, ilmenite, and rutile.

Such irregular variations are noted not only in closely related rocks but in different parts of the same rock mass, and, as in this case, correspond to variations in the proportions of the essential minerals.[a]

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[a] Iddings, J. P., 12th An. Rept., U. S. Geol. Survey, 1890-91, pt. 1, p. 630.

Analyses of nelsonites from Nelson County, Virginia.

(WM. M. THORNTON, JR., *Analyst.*)

	I	II	III	IV	V	VI	VII	VIII
TiO_2	15.78	16.48	37.00	37.68	41.46	42.84	65.90	69.67
	.198	.207	.462	.471	.518	.535	.824	.871
Fe_2O_3	31.45	43.34	4.31	2.70	15.59	11.12	3.65	2.87
	.235	.272	.027	.017	.098	.069	.023	.018
FeO	20.20	18.61	26.52	29.14	23.57	27.93	7.95	5.04
	.280	.258	.368	.405	.328	.388	.110	.069
MgO	0.64	0.66	1.11	0.50	0.50	0.72	0.25	0.15
	.016	.016	.027	.012	.012	.018	.006	.004
CaO	12.73	5.48	16.33	16.05	9.03	8.34	11.13	12.16
	.227	.098	.291	.286	.161	.149	.199	.217
P_2O_5	9.40	4.98	13.08	12.48	7.59	6.89	8.14	9.41
	.066	.035	.092	.088	.053	.048	.057	.066
H_2O-	0.20	0.51	0.09	0.03	0.53	0.15	0.21	0.09
H_2O+	0.97	1.62	0.59	....	0.87	0.58	0.35	0.11
F	0.23	0.26	0.98	1.03	0.17	0.21	0.34	0.70
	.012	.014	.051	.053	.011	.011	.018	.037
Cl	Trace	Trace	Trace	Trace	Trace	0.01	None	Trace
SiO_2	1.24	4.24	0.57	......	1.65	0.70	0.95	0.67
	.021	.071	.009		.027	.011	.016	.011
Al_2O_3	n. d.	3.45	.....	.....	.....	.....	.....	.....
		.034						
Na_2O	0.10	0.15	.....	.....	.....	.....	.....	.....
	.002	.003						
K_2O	0.34	0.45	.....	.....	.....	.....	.....	.....
	.003	.005						
MnO	0.23	0.12	0.38	Trace	0.26	0.18	0.26	.....
	.008	.001	.005		.004	.003	.004	
CO_2	.....	Trace	Trace	.....	Trace	Trace	Trace	.....
S	.. ..	Trace	1.45	1.17	.....	.....	1.61	0.34
			.045	.036			.050	.011
	99.51	100.35	102.41	100.78	101.22	99.67	100.74	101.21
Less O	0.09	0.11	0.79	0.72	0.07	0.09	0.54	0.39
	99.42	100.24	101.62	100.06	101.15	99.58	100.20	100.82

I. Magnetite-biotite nelsonite dike on the Dillard farm 2 miles southwest of Lovingston.
II. Magnetite-biotite nelsonite dike on John Stevens farm about half a mile west of Lovingston.
III. Ilmenite nelsonite from ore-dump at General Electric Co.'s mine, 1.75 miles northwest of Rose's Mill.
IV. Ilmenite nelsonite from ore-dump at General Electric Co.'s mine, 1.75 miles northwest of Rose's Mill. Probably taken from No. 1 vein in the adit level.
V. Ilmenite nelsonite dike on Hight place about 1.75 miles west of north from Roseland.
VI. Ilmenite nelsonite dike on Shelton farm about 1 mile northwest of Roseland.
VII. Rutile nelsonite dike on the Giles tract near Roseland.
VIII. Rutile nelsonite from ore-dump of adit level, General Electric Co.'s mine, 1.75 miles northwest of Rose's Mill.

The norms calculated from the analyses in the table on page 147, are given in the annexed table.

Norms of nelsonites corresponding to the analyses on page 147.

	I	II	III	IV	V	VI	VII	VIII
Quartz	.....	0.42	.....	.....	1.65	.....	.....	0.42
Orthoclase	.....	2.78	.....	.....	.....	.....	.....	.....
Albite	.....	1.57	.....	.....	.....	.....	.....	.....
Corundum	.....	2.65	.....	.....	.....	.....	.....	.....
Leucite	1.31	.....	.....	.....	.....	.....	.....	.....
Nephelite	0.57	.....	.....	.....	.....	.....	.....	.....
Hypersthene	.....	1.60	.....	.....	.....	1.10	.....	0.40
Diopside	.....	.....	.....	.....	.....	.....	1.79	.....
Olivine	0.70	.....	1.26	.....	.....	.....	.....	.....
Ilmenite	30.10	31.31	52.46	60.65	49.86	58.98	13.22	9.73
Magnetite	19.72	12.06	.....	.....	.....	.....	.....	.....
Hematite	23.04	35.20	4.32	2.72	15.38	11.04	3.68	2.88
Rutile		.....	9.36	5.76	15.20	11.76	58.96	64.56
Apatite	22.18	9.74	30.91	29.57	17.81	16.13	19.15	22.18
Pyrite	.....	.....	2.76	2.18	.....	.....	3.00	0.62
Water	1.17	2.13	0.68	0.03	1.40	0.73	0.56	0.20
	98.79	99.46	101.75	100.91	101.30	99.74	100.36	100.99
Less excess CaO				0.39				
				100.52				

Classification.

Old system of classification.—The range in mineral composition of nelsonite would be designated in the older terminology, as stated above, by the names *ilmenite nelsonite, rutile nelsonite, magnetite nelsonite, hornblende* or *biotite nelsonite,* and *gabbro-nelsonite,* the mineral prefixes denoting special richness in these minerals. As already stated, the normal nelsonite, the most abundant varietal form of the rock, is an even-granular mixture of ilmenite and apatite in somewhat variable proportions.

New quantitative system of classification.—The positions in the quantitative system of classification of the eight rocks corresponding to the norms in the table above may be expressed as follows:

No.	Symbol	Name proposed
I.	$\mathrm{V.}_{\mathrm{II.}}$ 5. (2)3. (2)3. (4–5).	Nelsonose
II.[a]		
III.	$\mathrm{V.}_{\mathrm{II.}}$ 5. 5. (2)3. 5.	
IV.	$\mathrm{V.}_{\mathrm{II}}$ 5. 5. (2)3. 5.	
V.	$\mathrm{V.}_{\mathrm{II.}}$ 5. 4. 2(3). 5.	
VI.	$\mathrm{V.}_{\mathrm{II}}$ 5. 4(5). 2. 5.	
VII.	$\mathrm{V.}_{\mathrm{II}}$ 5. 5. (1)2. 5.	
VIII.	$\mathrm{V.}_{\mathrm{II.}}$ 5. 5. 4. 5.	Virginose

[a] Either CaO is too low or P_2O_5 too high, which makes a difference in classification, so not figured out.

These are unoccupied positions in the new system of classification, but for reasons given in the discussion under individual varietal forms of nelsonite only two new names are suggested at this time.[a] As developed in the descriptions on pages 100 to 145, the rocks represented by the analyses in the table on page 147, and grouped under the field name nelsonite, are unique in composition and represent new and extreme ultrabasic igneous rock types. In composition they are all alike in containing apatite as one of the essential minerals. They are unlike as to rutile, ilmenite, or magnetite being the predominant dark ore mineral. The two types are represented by the analyses in columns IV and VIII of the table, the others being regarded more as gradational facies and therefore intermediate in composition between the two principal types.

As shown in the summary above, all the analyses of nelsonites, except hornblende nelsonite and gabbro-nelsonite (not included in the table of analyses above, page 147), fall into class V (perfemane), but into subrang positions of rangs, sections, and orders not yet named. It is therefore proposed that new names be given to those varietal forms of nelsonite which fall within the limits of the classificatory scheme.

The two analyses of hornblende nelsonite and the single analysis of gabbro-nelsonite are not included in the table of analyses on page 147, but are given under the separate descriptions of the two types on pages 135 and 140. The two analyses of hornblende nelsonite fall into class IV (dofemane) near class V (perfemane) but are classed as of IV. They occupy border positions in the classificatory scheme, hence it is thought best not to suggest a new name for them. The analysis of gabbro-nelsonite falls into class IV (dofemane) but into rang and subrang positions not yet named. The names *roselandase* and *roselandose* are proposed as appropriate rang and subrang names for this rock.

Referring to the table of analyses on page 147, IV and VIII represent analyses of fairly fresh material; I less fresh and more or less altered, as shown both under the microscope and by the analysis. Of these IV is the normal type, and since nelsonite was originally proposed by the senior writer for it, the subrang name *nelsonose* is suggested for its designation in the quantitative system. Likewise the subrang name *virginose* is proposed for VIII.

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[a] The analyses which follow on pages 125 and 135, of magnetite, biotite, and hornblende nelsonites are new and do not correspond to any known rocks, but since they occupy border positions in the classificatory scheme magmatic names are not suggested for them. It is probable that an analysis made on fresh specimens of magnetite-biotite nelsonite similar to the occurrence on the Dillard farm near Lovingston will remove the rock from a border position, which if true and is not then occupied, the subrang name *lovingstonose* is suggested as appropriate.

The positions of these two new rock types in the quantitative system may be summarized as follows:

No.	Symbol	Name
IV.	$\mathrm{V}\cdot_{\mathrm{II.}}5.$	virginare.
	$\mathrm{V}\cdot_{\mathrm{II.}}5.\ 5.$	virginore.
	$\mathrm{V}\cdot_{\mathrm{II.}}5.\ 5.\ 3.$	nelsonase.
	$\mathrm{V}\cdot_{\mathrm{II.}}5.\ 5.\ 3.\ 5.$	nelsonose.
VIII.	$\mathrm{V}\cdot_{\mathrm{II}}\ 5.$	virginare.
	$\mathrm{V}\cdot_{\mathrm{II.}}5.\ 5.$	virginore.
	$\mathrm{V}\cdot_{\mathrm{II.}}5.\ 5.\ 4.$	virginase.
	$\mathrm{V}\cdot_{\mathrm{II}}\ 5.\ 5.\ 4.\ 5.$	virginose.

These norms place the rocks in the perfemane class; No. IV in the calciminic section, and in the preferrous subrang; No. VIII in the docalcic section, and in the preferrous subrang. Since these are the first recorded representatives of the two subrangs, *nelsonose* (IV) and *virginose* (VIII) are suggested as appropriate subrang names. It is worthy of note that there are no known rocks which stand near *nelsonose* and *virginose.* Adirondackore and champlainore (titaniferous iron ores) are grouped in the dofemane class,[a] but resemble in chemical composition the Virginia rocks in containing high percentages of titanium and iron oxides.

Since I does not represent fresh material, and the norm gives it a border position in the quantitative system, it is thought best to await securing fresh material for a more satisfactory chemical analysis before proposing a name for it. In the event of a satisfactory analysis made of fresh material, *lovingstonose* is suggested.

Classification of nelsonites compared with that of titaniferous magnetites.—The Virginia nelsonites are probably more closely allied to the titaniferous magnetite ore-bodies of the eastern United States and northern Europe than to any other known type of rock. The two are essentially different and are strongly contrasted with each other in many particulars, yet they present some points of similarity. Because of this fact and for convenience of comparison we give in tabular form below the position in the quantitative system of four analyses of titaniferous magnetite ores from New York (3) and Sweden (1), which are regarded as igneous in origin.

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[a] Washington, H. S., Professional Paper No. 14, U. S. Geol. Survey, 1903, p. 365.

Quantitative classification of titaniferous magnetite ores.

Locality	Symbol	Name	Authority
Essex Co., New York.	IV. 4. 2. 1. 1. 4.	Adirondackiase	Washington's Tables, p. 364.
Essex Co., New York.	IV. 4. 3. 1. 1. 4.	Champlainiase	Washington's Tables, p. 364.
Sanford, New York...	V. 5. 2. 1. 1. 5.		Sch. M. Quart., XX, p. 344.
Taberg, Sweden.......	V. 3. 4. 1. 1. 2.		Sch. M. Quart., XXI, p. 60.

Genesis.

The nelsonite bodies of dikelike form, described in the preceding pages of this report, occur in the midst of rocks of igneous origin that have been intensely, though unequally, metamorphosed, and in which the nelsonites have also shared. The natural inference would be that the nelsonite bodies were likewise formed by igneous action. They are found principally in the syenite of the Roseland district, but occur also in a few places in the outside gneiss, and entirely in gneiss in the Lovingston district. The distribution of the nelsonite in the Roseland district is near the southeast border of the syenite (map, Pl. I).

The genetic relationship of the nelsonite bodies to the inclosing rocks is shown (1) by their close association, and (2) in the similarity of the minerals composing them. The principal minerals in the nelsonite bodies have been shown to be ilmenite, rutile, magnetite, and apatite, together with the same accessory silicate minerals that form the chief constituents of the surrounding rocks. However, the occurrence of silicate minerals in the nelsonites is extremely irregular in distribution and amount, oftentimes present if at all in such minute quantity as not to be observed in hand specimens, and even in thin sections only a sporadic grain may be identified. On the other hand they are frequently present in amount as to be readily recognized in hand specimens as well as in thin sections of the rock.

The ore minerals composing the nelsonite bodies likewise enter into the composition of the inclosing rocks as minor accessory minerals. Between these two extremes are dikes of gabbro-nelsonite, composed of large but unequal proportions of silicate and ore minerals, which may be considered as the connecting link between the nelsonites proper and the gabbroic type of silicate rocks. In general then the rocks differ from each other in mineralogy more in the proportion than in the kind of minerals composing them.

The field evidence gained from a study of exposures of, and openings made in, the nelsonite bodies is sufficient to indicate their general form or outline. They show marked irregularity in direction of both dip and strike but, in general, they are roughly tabular in form with the longer axis parallel to direction of strike. In most cases they appear to conform to the structure of the inclosing rock, but there are a few instances in which they cut across the structure. Some afford evidence of gradation at the walls into the inclosing rock while others show sharply defined contacts or walls, with complete differentiation of nelsonite and inclosing rock.

A conspicuous feature of the nelsonite bodies, especially the dominant or normal variety ilmenite nelsonite, is their remarkably uniform granularity from wall to wall, the size of grain being entirely independent of width of the body. Wherever observed in the numerous bodies the size of grain is the same at the contacts as in the center and is uniform for both large and small bodies, whether 1 foot or 60 feet in width. Another feature is the entire lack of contact phenomena along the walls of these bodies. These characteristics, especially that of uniform granularity, together with that of sharp boundaries, are regarded as indicative of the conditions under which they were formed, namely, intruded at depth into the still hot and possibly unsolidified rocks inclosing them. Under these conditions it is conceived that all portions of the nelsonite magma were free to solidify uniformly.

In a few instances the nelsonites, especially those of the rutile variety, are banded, layers of apatite alternating with those containing the dark titanium minerals chiefly rutile—a structure similar to that shown in some magnetites of the eastern United States and northern Europe, whose origin is now generally agreed to be igneous. The banded structure, however, in the Virginia nelsonites is the exception, for vastly the majority of them do not afford the slightest evidence of such structure, but are entirely massive granular.

The rutile (high titanium) nelsonites afford evidence of having formed somewhat in advance of the lower titanium-bearing or ilmenite nelsonites, as they often have the appearance of segregations rather than instrusive bodies because of their gradations along the walls into the inclosing syenite. They are regarded as having formed practically contemporaneously with the syenite by a process of differentiation in place (magmatic segregation). On the other hand the ilmenite nelsonites which usually exhibit sharp boundaries, probably represent intrusives at great depth into the still hot rocks either before or soon after complete solidification, for the ore-bodies are remarkably uniform in granularity from wall to wall, indicating that all portions of the mass solidified practically uniformly.

The magnetite and biotite nelsonites which penetrate the outside gneiss frequently show evidence of segregation along the walls, and difference in the proportion of minerals in the center and along the border portions of the bodies.

From the evidence at hand, therefore, it seems probable that some of the nelsonite bodies, especially those of the rutile variety, separated in place from the cooling magma, while others, such as the ilmenite variety, probably formed a little later but at great depth, possibly before the magma giving rise to the inclosing rock had solidified, and while it was still hot. While these differences are shown in places, the general principle underlying the formation of these bodies is not affected by possible minor variations in details of genesis, whether some represent differentiation in place and are normal magmatic segregations, and others were formed later but before the magma had solidified, representing possibly an intermediate type between true magmatic segregations and normal igneous intrusions.

Broadly interpreted from present available evidence the writers regard the formation of the nelsonite bodies to have been due to processes more closely allied to magmatic segregation than to true dike form of intrusion. Their formation in other words is regarded as a segregation or differentiation facies of the igneous rocks inclosing them, somewhat similar in mode of genesis to the well-known titaniferous magnetite ore-bodies in gabbros and anorthosites, with which they present many points of similarity. They represent differentiations from the magma which gave rise upon cooling to the syenite and other igneous rock types in the area.

Additional evidence in favor of this hypothesis is furnished by the distribution of the ore-bodies within the syenite area; the nelsonites are, for the most part, strung out near the southeastern border as are also those portions of the syenite which are most highly titaniferous—such as the deposits on the property of the American Rutile Company.

It was thought that accurate determinations made of the melting points of the principal minerals (ilmenite, rutile, and apatite) of the nelsonite bodies, when compared with the melting points of the same minerals known to have formed by processes other than igneous, might possibly shed some light on the genesis of the rock. A careful search of the literature unfortunately indicated that trustworthy data bearing on this subject were very meager, so that conclusions based on a comparison of the melting point of the same mineral formed under different conditions can not be stated at this time.

Carefully prepared specimens of the rutile, ilmenite, and apatite of the nelsonite, and of rutile from the syenite, were separated from the rocks and cleansed as thoroughly as possible, and sent to the Bureau of Standards, Washington, D. C., for an accurate measurement of their melting points. The results, including a similar determination made on one of the rocks (ilmenite nelsonite), are tabulated below.

Table of melting points of rutile, ilmenite, and apatite from Nelson County, Virginia.

(Determined by the Bureau of Standards, Washington, D. C.)

No.	Rock	Mineral	Melting Point in degrees C.
1	Nelsonite	Rutile	1700
2	Nelsonite	Ilmenite	1390
3	Nelsonite	Apatite	1690
4	Syenite	Rutile	1690
5	Nelsonite (variety ilmenite)	Ilmenite and apatite	1365

A statement of the methods used in determining the melting points of the five samples tabulated above was communicated to the State Geologist, in 1910, by Dr. W. F. Hillebrand, Acting Director, Bureau of Standards. It follows:

> The specimens were heated in a graphite resistance vacuum furnace. They were placed in platinum crucibles except in the case of the apatite, which was heated in graphite crucibles and, in one case, in a magnesia crucible. The minerals were adequately protected from any carbon monoxide or other substances given off by the graphite heater, except in the case of the apatite. However, this did not appear to be contaminated. The temperatures were determined with an optical pyrometer.
>
> Two methods of determining the melting point were used: In one the mineral was heated in an open crucible and the point at which it flowed was observed visually. This method is not always reliable because some minerals are so viscous when melted that they do not flow visibly until the temperature is considerably above their melting points. In this method, there is also a chance of an error of a few degrees, owing to the fact that the radiation from the inside of an open crucible may not be exactly that of a black body.
>
> In the other method, which is the more reliable, the crucible was covered, save for a small opening through which the temperature was observed, thus giving black body conditions, and a heating curve was plotted.
>
> The results by the two methods were always in close agreement, for it happens that all the minerals submitted became quite fluid when melted. The melting points are quite sharply defined, except that of the rock, No. 5, which is a little less sharply defined than those of the other specimens, as was to be expected from its heterogeneity.

> In the case of many minerals, the corners of sharp fragments are rounded at temperatures considerably below the true melting point, indicated by the heating curve. This occurred in the case of the apatite and the rutile samples, and apparently to some extent in the case of the ilmenite. The sintering of powders at temperatures below the melting point was also observed. But in all cases except that of No. 5 the change from a solid with rounded corners to a liquid of quite low viscosity was very distinct and definite.

In October, 1911, Mr. W. M. Slater,[a] President, American Rutile Company, submitted a sample of his high-grade rutile concentrates (95-98 per cent TiO_2) to the U. S. Bureau of Standards for measuring the melting point. The rutile was found to melt at 1715° C., but under certain conditions melting was observed as low as 1690° C., which Director Stratton stated was very likely the result of slow decomposition of the TiO_2 into a lower oxide of titanium.

Summary of Quantitative Classification of Nelsonites.

The six varietal forms of nelsonite recognized in the Amherst-Nelson counties region and described in the preceding pages of this report represent new rock types. For reasons previously stated new names in the quantitative system are proposed at this time for only three of the six types. These may be summarized below as follows:

Symbol	Old name
$\mathrm{V}_{\cdot\mathrm{II}}.5.$ virginare.	Ilmenite nelsonite.
$\mathrm{V}_{\cdot\mathrm{II}}.5.\ 5.$ virginore.	
$\mathrm{V}_{\cdot\mathrm{II}}\ 5.\ 5.\ 3.$ nelsonase.	
$\mathrm{V}_{\cdot\mathrm{II}}.5.\ 5.\ 3.\ 5.$ nelsonose.	
$\mathrm{V}_{\cdot\mathrm{II}}.5.$ virginare.	Rutile nelsonite.
$\mathrm{V}_{\cdot\mathrm{II}}.5.\ 5.$ virginore.	
$\mathrm{V}_{\cdot\mathrm{II}}.5.\ 5.\ 4.$ virginase.	
$\mathrm{V}_{\cdot\mathrm{II}}.5.\ 5.\ 4.\ 5.$ virginose.	
$\mathrm{IV}_{\cdot\mathrm{II}}\ 3.\ 1.\ 2.$ roselandase.	Gabbro nelsonite.
$\mathrm{IV}_{\cdot\mathrm{II}}.3.\ 1.\ 2.\ 3.$ roselandose.	

Diabase.

INTRODUCTORY STATEMENT.

The rocks grouped under this heading occur only as dikes. They show in thin sections under the microscope the development of two contrasted textures, diabasic (ophitic) and fine, even-granular, corresponding to diabase proper and basalt, respectively. They are closely similar in mineral composition and are grouped here under the single heading, with a statement of the kind of texture of each noted in the description of individual occurrences.

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[a] Personal communication from Mr. Slater, Dec. 4, 1911.

DISTRIBUTION AND LITHOLOGIC CHARACTERS.

Diabase dikes varying in width from a fraction of an inch to 25 feet and over occur at many places in the area. They are the youngest of the series of intruded rocks and may be found penetrating all the earlier formations. They are confined chiefly to the rutile-bearing rocks of the large syenite area, but are observed in several places cutting the surrounding gneiss. (See Pls. XXII, XXIII, and XXIV, for photographs of diabase dikes near Roseland.)

They are fine-grained rocks, dark gray to almost black in color, which show under the microscope fine, even-granular (basalt) to typical ophitic (diabasic) texture, and the principal minerals plagioclase feldspar, augite, and titaniferous magnetite. The sulphides, pyrite and pyrrhotite, are usually present in small quantity. In common with other rocks of the area the diabase shows evidence of metamorphism but not to the same extent. Megascopically the only alterations observable are the production of epidote and the development in some instances of a slight schistose structure. No gradational rocks intermediate in composition between diabase and the other rock types occur and there was evidently a considerable time interval between the formation of the earlier rocks and the intrusions of diabase. The former rocks solidified under conditions of deep burial, but the latter (diabase) were not intruded until much overlying material had been removed and the rocks were nearer the surface, for in many places they follow joint-planes and fractures in the older rocks.

MICROSCOPIC CHARACTER.

Examined in thin sections under the microscope the intrusive rock is found to contain augite partially or wholly altered to hornblende, plagioclase feldspar, magnetite, a little orthoclase, and apatite. Sometimes olivine and biotite are also present in small amounts, and scattered grains of pyrite are noted. Clusters of minute brown rutile crystals were observed in thin section No. 144. The secondary minerals are a little leucoxene, minute, granular, black iron oxide, and less commonly chlorite, pale green fibrous amphibole (uralite), pleochroic brown biotite, epidote, and zoisite. Calcite was not identified among the secondary products in thin sections.

The texture of the rocks is variable, ranging from fine granular, in which the chief minerals are formed in grains of approximately equal size and of nearly equal dimensions, to typical diabasic or ophitic, in which the augite fills the interstices between the interlacing lath-shaped feldspars. On the basis of micro-texture the rocks grouped here under diabase would be more accurately classified into (a) basalt of fine-grained, even-granular texture, and (b) diabase of pronounced ophitic texture. In each of these types the larger augites, feldspars, and occasional olivines, are sometimes scattered through a fine-grained ground-mass constituting a micro-porphyritic (basalt-porphyry) facies. With only one exception (Spec. 144) the thin sections show an advanced stage of alteration in the augite (uralitization), alteration of augite into hornblende. Along with uralite more or less secondary biotite also is sometimes formed. Alteration of these into chlorite is less often observed. A second evidence of metamorphism is apparent in some thin sections in mashing of the feldspars, and, while schistosity was not manifested microscopically, it is developed to a slight degree in some hand specimens.

Augite, the most abundant constituent, is partially or wholly altered into a pale green fibrous amphibole, and when fresh is pale green to colorless, rarely exhibiting faint pleochroism. It occurs in small plates and irregular grains. Plagioclase feldspar, the second most abundant mineral, occurs in nearly equant grains in the even-granular facies of the rock, and in elongated, relatively narrow forms in the diabasic facies. Extinction angles measured against the twinning lamellæ indicate a plagioclase corresponding in composition to an acid labradorite. Magnetite, the next most abundant constituent to the plagioclase feldspar, varies greatly in amount and is usually in smaller grains than the other two minerals. Alteration to leucoxene indicates that the magnetite is of the titaniferous variety. Secondary black iron oxide, probably magnetite, derived from the alteration of augite, is observed in minute granules in the substance of the alteration products of the augite. Olivine is entirely absent with two exceptions (Specs. 124 and 144) from the thin sections examined. It often shows crystal outline and presents no noteworthy features. The remaining minerals occur only in subordinate amount and since they present no unusual features they do not merit separate description.

CHEMICAL COMPOSITION AND CLASSIFICATION.

The chemical composition of the diabase is shown in four analyses given in tabular form below, made on specimens collected from dikes exposed in the vicinity of Roseland and Rose's Mill, along the southeast side of the syenite mass.

Analyses of diabase from Nelson County, Virginia.

(WM. M. THORNTON, JR., *Analyst.*)

	I	II	III	IV	V
SiO_2	48.99	49.65	52.34	52.83	50.95
Al_2O_3	13.93	13.93	12.46	13.79	13.53
Fe_2O_3	2.45	4.11	3.37	4.42	3.59
FeO	10.94	9.78	10.08	7.86	9.67
MgO	6.29	4.89	3.97	5.61	5.19
CaO	10.02	9.05	7.88	8.99	8.99
Na_2O	2.59	2.86	2.26	2.42	2.53
K_2O	0.80	1.71	1.66	1.46	1.41
H_2O-	0.09	0.09	0.14	0.71	0.26
H_2O+	1.47	1.49	1.46	1.30	1.43
TiO_2	3.33	3.03	2.96	1.18	2.63
P_2O_5	0.33	0.32	1.19	0.31	0.54
MnO	0.11	0.14	0.11	n. d.	0.09
S	Trace	0.20	0.18	Trace	0.09
CO_2	Trace	Trace	Trace	Trace	Trace
	100.34	101.25	100.06	100.88	100.90
Specific gravity..	......	......	3.097	......	......

I. Diabase (basalt) dike on south side of Piney River, opposite General Electric Co.'s mine, 1.5 miles northwest of Rose's Mill.
II. Diabase (basalt) dike, Roseland-Arrington road, near Mr. Adams' house, 100 yards south of Roseland post-office; dike 25 feet wide, strike S. 80° W.
III. Diabase (basalt) dike, east side of Tye River, 425 feet south of American Rutile Co.'s south quarry; width 8 feet, strike N. 25° E.
IV. Diabase dike, east side of county road, 100 yards north of Piney River at Rose's Mill.
V. Average of I, II, III, and IV.

The norms calculated from the analyses above are tabulated as follows:

Norms corresponding to analyses on page 158.

	I	II	III	IV
Quartz	0.42	1.26	11.10	6.96
Orthoclase	5.00	10.01	10.01	8.34
Albite	22.01	24.10	18.86	19.91
Anorthite	23.91	20.29	18.90	22.80
Diopside	20.42	19.24	11.14	16.32
Hypersthene	17.30	11.96	14.89	15.27
Magnetite	3.48	6.03	4.87	6.26
Ilmenite	6.38	5.78	5.62	2.28
Apatite	0.68	0.62	2.48	0.62
Pyrite	.....	0.36	0.36	.....
H_2O	1.56	1.58	1.60	2.01
	101.10	101.23	99.83	100.77

The rocks corresponding to the calculated norms have the following position in the quantitative system of classification:

No.	Symbol	Name
I.	III. 5. 3–4. 4–5.	Camptonose-auvergnose.
II.	III. 5. 3. 4.	Camptonose.
III.	′III. 4. 3. ′4.	Vaalose.
IV.	′III. ′5. 3′. 4.	Camptonose.

The analyses indicate close similarity in chemical composition of the diabase, which is further emphasized by the fact that, in the quantitative system of classification, three of the four (I, II, and IV) have approximately the same position. The norm of III shows more quartz, and the quartz-feldspar ratio places it in order 4 instead of in order 5 with I, II, and IV. The rocks are dosodic, and the albite-anorthite ratio in each corresponds closely to a plagioclase of the composition Ab_1An_1 (labradorite). The analyses are noteworthy for the high percentages of TiO_2, especially in I, II, and III, and of P_2O_5 in III. The slightly increased percentage of MgO in I is accounted for by the presence of some olivine in the rock. With these exceptions the analyses conform closely to diabase of the normal type.

DETAILS OF OCCURRENCES.

Detailed descriptions of the diabase dikes occurring on the property of the American Rutile Company, at Roseland, and in the mine of the General Electric Company, near Rose's Mill, are given on pages 168 and 192, and will not be repeated here. The brief descriptions which follow below are of diabase dikes occurring at other places within the area mapped.

Just across Piney River from the mine recently worked by the General Electric Company diabase is exposed in the bluff bordering the lowlands near the river. The rock (Spec. 124) is fine-grained and dark blue-gray, almost black, in color. Feldspar, chlorite, magnetite, and graphite (?) may be distinguished with the pocket lens. In thin section under the microscope the rock is seen to be considerably altered but the diabasic texture is shown. It is an olivine diabase, composed of the principal minerals augite, soda-lime feldspar (labradorite), magnetite, and olivine. Augite is largely altered to pale blue-green hornblende (uralite) and olivine to chlorite, each accompanied by the separation of minute grains of black iron oxide in the substance of the hornblende and chlorite. A chemical analysis of this rock is given in column I of the table of analyses on page 158.

On the east side of the county road, about 100 yards north of the river at Rose's Mill, is a large exposure of biotite gneiss penetrated by several dikes of diabase which range from a fraction of an inch up to 5 feet in width. The smaller dikes appear to be off-shoots from the large one, which contains near its border unaltered inclusions of the gneiss. It is a dark gray rock (Spec. 130) with small lath-like phenocrysts of feldspar and contains a little pyrite or pyrrhotite. Microscopically the rock is porphyritic and diabasic in texture, composed chiefly of augite, soda-lime plagioclase (labradorite), titaniferous magnetite, and some biotite. Both the augite and plagioclase feldspar are partly altered. A chemical analysis (column IV of table of analyses) and the norm of this rock are given on page 158.

About half a mile northwest of Roseland an altered diabase dike, 10 feet wide and striking N. 15° E., is exposed in a deep road cut. The rock is completely weathered near the surface, but a specimen (Spec. 21) obtained from a piece of float near the outcrop shows a fine-grained, dark gray, slightly schistose diabase, containing a little pyrite. Under the microscope a thin section of the rock shows fine even-granular rather than diabasic texture—a texture more characteristic of basalt than of diabase. The principal minerals are secondary pale green hornblende (uralite) derived from augite, soda-lime plagioclase (labradorite) greatly altered, and much leucoxene derived from titaniferous magnetite or ilmenite. Augite is completely altered to hornblende, which is the most abundant mineral, and the feldspar shows mashing and advanced alteration.

INDIVIDUAL DESCRIPTION OF MINING PROPERTIES.

GENERAL STATEMENT.

While several properties in the Roseland district have been prospected for rutile actual mining operations have been limited to two localities. The principal and most extensively worked property lies a quarter of a mile south of Roseland on Tye River, where the American Rutile Company has been mining and milling rutile in syenite since 1902. So far as mining operations extend the rutile associated with the feldspathic facies of the syenite on this property is essentially free from ilmenite or other metallic minerals, but that associated with the quartz and hornblende of the hornblendic facies of the rock is more likely to be mixed with ilmenite. The other property, on the Warwick tract lying on the north side of Piney River one and a half miles northwest of Rose's Mill, was formerly worked by the General Electric Company, but has been idle since 1909. Mining of rutile by the General Electric Company at this locality was limited to the rutile-bearing nelsonite bodies. Unlike the syenite near Roseland in which are opened the quarries of the American Rutile Company, the syenite on the Warwick tract contains rutile in very sparing quantity, frequently not visible to the naked eye in hand specimens, and nowhere observed even approaching concentrations that might be workable.

Detailed individual descriptions of these two mining properties follow below in the order named.

AMERICAN RUTILE COMPANY'S QUARRIES.

LOCATION AND HISTORY.

The rutile-bearing lands of the American Rutile Company lie on both sides of Tye River about a quarter of a mile south of Roseland Post-office. As yet mining operations have been confined to the east side of the river and to the immediate vicinity of the mill. A topographic and geologic map of the property showing the open cut workings (quarries) and mill buildings is given in fig. 11.

A historical summary of the mining developments and operations by the American Rutile Company is given on page 49. Developments were begun by this company on its property located a quarter of a mile south of Roseland in 1900, and in 1902 a stamp mill of 50 tons daily capacity was erected for crushing and concentrating the ore. Practically all the rutile used in this country since 1901 has been supplied by the above company from its Nelson County deposits, and much of the product has been shipped abroad.

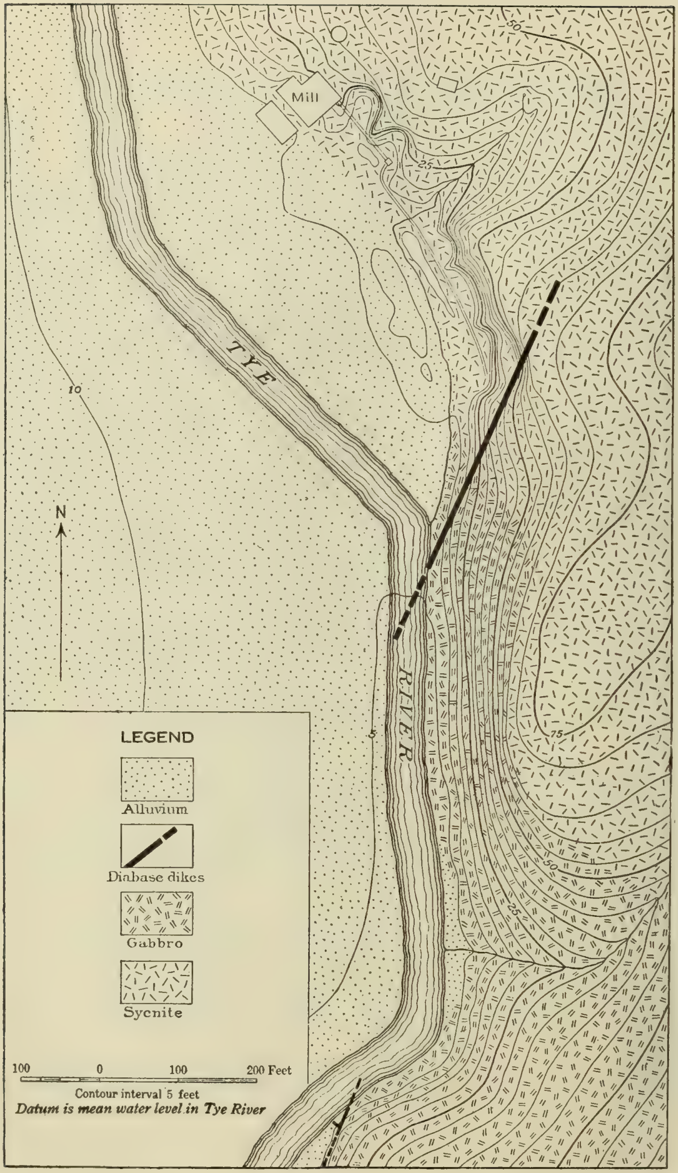


Fig. 11.—Topographic and geologic map of the American Rutile Company's property, Nelson County.

PRODUCTION AND USES.

Beginning with the year 1903, the total annual production of rutile to date by the American Rutile Company is given in tabular form on page 51. Although the consumption of rutile has increased since 1903, the demand has been limited and not sufficient to keep the mill in continuous operation.

The various uses made of rutile are discussed in detail on pages 270-289. For the prices paid for rutile the reader is referred to the statement made on page 52.

GEOLOGICAL RELATIONS.

The topography and geology of the American Rutile Company's property worked for rutile are well shown on the accompanying map, fig. 11. The line of bluffs, ranging up to 50 feet in height which border the river on the east side and in which are opened the quarries yielding the ore, afford good exposures of the rocks. The mantle of rock decay is not uniform in thickness and often contains large residual masses of unweathered rock, which usually carries more quartz than the average syenite of this vicinity. The rocks are weathered to a depth of 20 feet in places, so that a short distance back from the stream exposures of fresh rock are rarely observed. As a result of weathering considerable loose rutile is more or less concentrated in places on the surface and in the mantle of decayed rock. Because of the very favorable conditions much of the surface mantle of rock decay could probably be worked profitably by the methods of hydraulic mining.

Syenite.

As indicated on map, fig. 11, the quarries from which rutile is mined by the American Rutile Company are located in the syenite body very close to its eastern margin. Openings are made in both the feldspathic and hornblendic facies of the syenite, and while rutile occurs in each facies of the rock it is most abundant in the feldspar-rich syenite and probably contains less associated ilmenite.

The syenite is a coarsely crystalline igneous rock composed essentially of white feldspar with variant blue quartz in the feldspathic facies, and much secondary hornblende (uralite) in the border or hornblendic facies. The ratio of these minerals is variant, feldspar being greatly in excess in the feldspathic facies and in places forms the entire rock mass, while hornblende is very conspicuous in the border or hornblendic facies. Blue quartz is usually present in small grains, forming in places a considerable proportion of the rock and in others it is practically absent. Hornblende is practically absent from the feldspathic facies of the rock, but is a dominant mineral in the border or hornblendic zone. Rutile in deep red grains of adamantine lustre, associated with some ilmenite and in a few places apatite, occurs as a prominent constituent in portions of the rock. It varies in amount from zero in some sections up to probably 10 per cent and more in certain restricted areas. In the quarries opened and worked by the company, rutile will probably average 4 or 5 per cent of the rock mass. The general character and mode of occurrence of the rutile, including chemical analysis, are described on pages 193-196. Ilmenite, including chemical analysis, is discussed on pages 223-226. Pyrite has been observed in places as a very minor accessory mineral. The rock has been subjected to intense metamorphism as indicated in the granulation of the feldspar and quartz, in the partial segregation of the rutile and hornblende. and in the more or less distinct schistose structure, especially of the hornblendic facies.

In the northwest quarries lying nearest the mill, the syenite is practically free from hornblende and other iron-bearing minerals, but the rock exposed in the southeast quarries contains much hornblende and some ilmenite.

The feldspathic facies of the syenite exposed in the open cuts (quarries) and represented by specimens 1, 2, 3, and 4, is composed dominantly and in places almost exclusively of white feldspar, chiefly andesine with intergrowths of microcline or orthoclase. Blue quartz is usually present but varies greatly in amount, and appears to increase in quantity and size of grain toward the southeast, where it becomes most abundant in the hornblende or border facies of the rock. Rutile in disseminated grains is usually present and in limited areas forms a notable percentage of the rock mass. The rutile grains range up to 3 mm. in diameter and are often distributed along broken lines with their longest diameters approximately parallel, imparting a slightly gneissic appearance to the rock. The feldspar often shows large cleavage faces, sometimes 25 to 30 square centimeters in area, on which fine multiple twinning can be distinguished with the aid of a pocket lens. The cleavage faces are usually bent into curved surfaces, and in other ways show the effects of great stress subsequent to their crystallization.

In places the syenite is cut by veinlets, approximately parallel, spaced from a quarter of an inch to one inch apart, and ranging in thickness up to a sixteenth of an inch, but are usually of almost paper thickness. They are not exactly parallel since they sometimes branch and run into one another. The veinlets cut across the foliation of the rock and pass through quartz and rutile as well as the feldspar. They seem to be composed almost entirely of feldspar similar in composition to that of the rock (syenite) traversed, but a rutile grain was found in one of the largest of them. They are more resistant to weathering than the inclosing rock and therefore stand out in relief on a weathered rock surface. The rock fractures more readily along these planes than in other directions. Although they are called veinlets, it is possible that they may be due to some alteration that has taken place along parallel fracture planes.

The hornblendic facies of the syenite (Specs. 5 and 6) is exposed in the southern quarries, which show a coarsely crystalline rock composed of hornblende, blue quartz, and feldspar, with scattered grains of rutile and some ilmenite inclosed in the three principal minerals. The ilmenite seems to be largely confined to the hornblende and to a less extent the quartz. The rutile occurring in the hornblende has a somewhat darker color than that found in the other two minerals. The grains of both rutile and ilmenite range up to 5 mm. and more in diameter, and average somewhat larger in size than those found in the feldspathic facies of the syenite exposed in the north quarries. The blue quartz varies from microscopic grains up to masses weighing several pounds and is more abundant than in the hornblende free rock. Aside from its color it presents no unusual features. The hornblende is usually dark green in color, often fibrous with silky lustre, and occurs in masses of very irregular outline ranging up to 10 cm. and more in diameter. The different masses of hornblende are usually connected by irregular streaks or stringers of the same material in a manner suggesting secondary origin. (See Pl. XXIII, fig. 2.)

A detailed description (including megascopic and microscopic characters, chemical composition, and classification), of both the feldspathic and hornblendic facies of the syenite is given on pages 68-84, and will not be repeated here.

Gabbro.

Several hundred feet southeast of the south quarries of the company, a body of uralitized gabbro is exposed along the east side of Tye River, lying between biotite-quartz monzonite-gneiss on the southeast and the border zone of the syenite on the northwest. The gabbro grades into the hornblendic or border zone of the syenite on the northwest side, but, owing to the depth of residual decay, its relations to the biotite-quartz monzonite-gneiss on the southeast side could not be determined. Both the syenite and gabbro have undergone intense dynamic metamorphism which has resulted in crushing and bending of the individual minerals and the production of pronounced foliation or banding in much of the rock. Because of the development of banded structure in much of the gabbro mass, the rock in many places is more properly designated a gabbro-gneiss. In a few restricted areas the rocks have been so crushed and sheared as to develop schists from the original igneous types. Inequality of metamorphism as expressed in structure secondarily developed is a marked feature in both the gabbro and syenite.

So far as present exposures indicate, the gabbro mass is not lithologically uniform but is characterized by marked variations due chiefly to metamorphism. Variations in structure are from a rock nearly massive to completely foliated or banded; in texture from fine- to coarse-grained; and in color from medium to dark gray and grayish-green, according to the kind and relative proportions of the dark- and light-colored minerals. Variation in mineral composition of the rock is primarily one more of difference in ratios of principal minerals and the resulting secondary ones than of kind, and yet differences in kind of minerals, usually of minor importance only, are noted.

Individual descriptions of hand specimens including the results of microscopic study collected from different points in the gabbro mass along the east side of Tye River will serve to emphasize the general character of the rock.

Specimen 12, taken from the gabbro near the diabase dike described on page 168, is a coarsely crystalline rock exhibiting pronounced banding, and is largely composed of feldspar and hornblende arranged in roughly parallel bands, with a little blue quartz, and small grains of ilmenite and probably rutile. A little graphite, pyrite, and pyrrhotite can also be distinguished. Passing north or east from the point where the specimen was taken, the rock appears to grade into typical syenite, while toward the south the blue quartz disappears and the rock becomes finer grained and less schistose as shown in specimen 13, described below. Microscopically a thin section of the rock shows it to be composed of fibrous uralitic hornblende derived from pyroxene with the separation of grains of black iron oxide and the principal feldspar, andesine, intergrown with microcline, a little quartz containing needle-like inclusions of rutile, much ilmenite partly altered to leucoxene, and some secondary colorless mica derived from feldspar. An analysis of this rock is given in column IV on page 95.

Specimen 13, collected about 100 feet south of No. 12, is a fine-grained, dark, greenish-gray rock with irregular light brown blotches of feldspar about 3 mm. in diameter, and without indications of foliation in the hand specimen. Megascopically hornblende, feldspar, and small grains of ilmenite and rutile with very little if any quartz are distinguishable. Under the microscope a thin section of the rock is identical in composition with specimen 12 except that additional brown biotite and apatite in separate individuals occur. Feldspar and quartz show granulation from mashing, and much of the feldspar exhibits bent and broken lamellæ. An analysis of this rock is given in column III on page 95.

Specimen 14 is a schist derived from the gabbro by intense local shearing and crushing. The specimen is much weathered but is the best that could be obtained. There is no sharp line separating the schist from the surrounding gabbro but gradation from one to the other is observed. Under the microscope a thin section of the rock shows it to consist essentially of uralitic hornblende partly fibrous, brown biotite, unstriated feldspar (probably andesine), a little quartz, apatite, and much ilmenite partly altered to leucoxene. Pronounced foliation is exhibited in the thin section and granulation of the light-colored minerals is observed.

On the east side of the river about 500 yards south of the present openings (quarries) of the company an unusually large mass of rutile is exposed, weighing possibly 100 pounds or more. The rock in the immediate vicinity is gabbro (similar to specimen 13 described above) containing scattered grains of rutile which increase in number and size as the main mass is approached. With this increase in rutile the gabbroic rock grades into one of syenitic character of unknown but probably limited extent, and it is in the latter that the rutile is principally found. The occurrence may be explained as a local segregation in the gabbro.

A dike of diabase 2 to 4 feet wide cuts the rocks at this point but its intrusion has no apparent relation to the rutile. The contact of the diabase with the inclosing rocks, where exposed, is sharp and somewhat irregular, following joints in the intersected rocks, and without evidence of contact metamorphism. In places both the gabbro and diabase are altered by dynamic metamorphism resulting in the production of a schist from the gabbro similar to specimen 14 described above, and from the diabase an epidote-bearing rock. Microscopically a thin section of the rock (Spec. 15) shows a typical schist composed almost exclusively of fibrous uralitic hornblende carrying inclusions of apatite and other minute colorless forms, together with minute grains and dustlike particles of black iron oxide. Large grains of ilmenite or magnetite occur.

Numerous cavities are formed in the large mass of rutile which have resulted from the removal of some other mineral, probably feldspar or apatite.

Between Roseland Post-office (about 100 yards south) and the American Rutile Company's mill is a large exposure of normal gabbro in and along the county road, cut by a dike of diabase 25 feet in width and having a general strike of N. 80° E. The line of contact between the two rocks is sharply defined and follows quite closely the jointing in the gabbro, the details of their relationship being clearly shown in the outcrop on the river bank just below the road (Pl. XXII, figs. 1 and 2). There is no evidence of contact phenomena. As exposed in the road cut, the gabbro extends for a distance of about 50 yards from the diabase and then grades into the feldspathic facies of the syenite, which at this point is composed almost entirely of feldspar. Near the river the rocks are well exposed and only slightly altered from weathering, but, a few yards away, they are completely covered by a mantle of residual rock decay, so that it is impossible to trace the dike for any distance along the strike.

Megascopically the gabbro is a medium gray, even-granular rock, exhibiting very slight schistose structure, and composed chiefly of plagioclase feldspar, 2 to 3 mm. in diameter, with fine twinning striae, smaller crystals of the dark ferromagnesian mineral, and numerous scattered grains of ilmenite measuring about 1 mm. in diameter. Microscopic study of a thin section of the gabbro shows the principal minerals to be pyroxene chiefly hypersthene altering peripherally to hornblende, andesine with spindle-shaped intergrowths of microcline, a few scattered grains of microcline, ilmenite altering to leucoxene, rutile, apatite, and inclosures of quartz in the feldspar (see page 95). An analysis of the rock is given in column II on page 95.

Diabase.

Several dikes of diabase (basalt) are noted cutting the rocks described above at different localities on the property of the American Rutile Company. These are separately described below.

Just south of the open cuts (quarries) of the company on the east side of Tye River a diabase dike about 8 feet wide and having a strike N. 25° E., can be traced northeast from the river for a distance of about 125 yards. It cuts both the gabbro and syenite and extends across the upper face of the quarry (Pls. XXIII and XXIV), but there is no evidence of contact metamorphism. The contact of the diabase with the gabbro is well defined but somewhat irregular in places. The diabase (Spec. 11) is a fine-grained, dark bluish-gray almost black rock, in which pyrite and small grains of ilmenite or magnetite may be recognized by means of a pocket lens. A thin

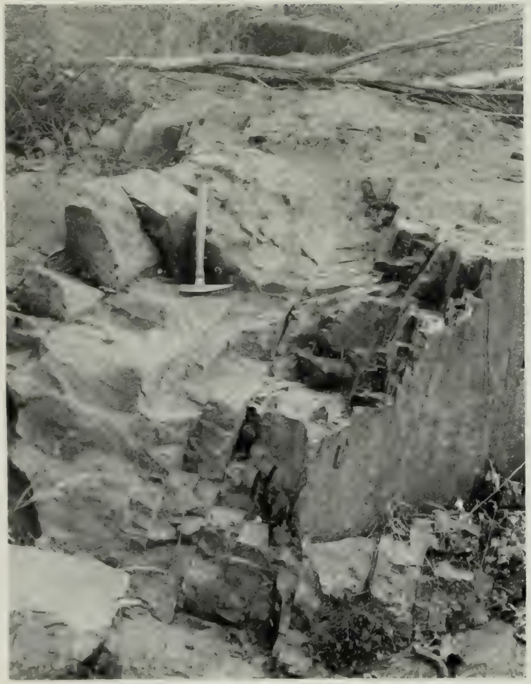


Fig. 1.—Outcrop showing contact between diabase dike and gabbro, between Roseland and the American Rutile Company's quarries. The line of contact follows joints in the gabbro.

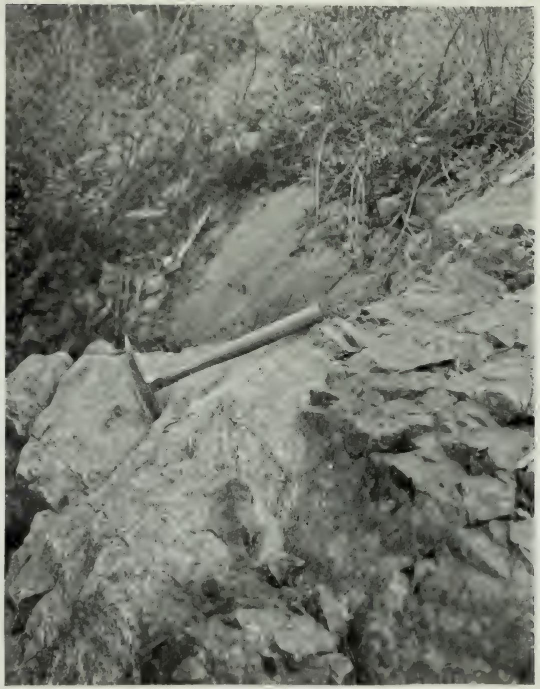


Fig. 2.—Detailed view of same outcrop.

CONTACT BETWEEN DIABASE AND GABBRO.

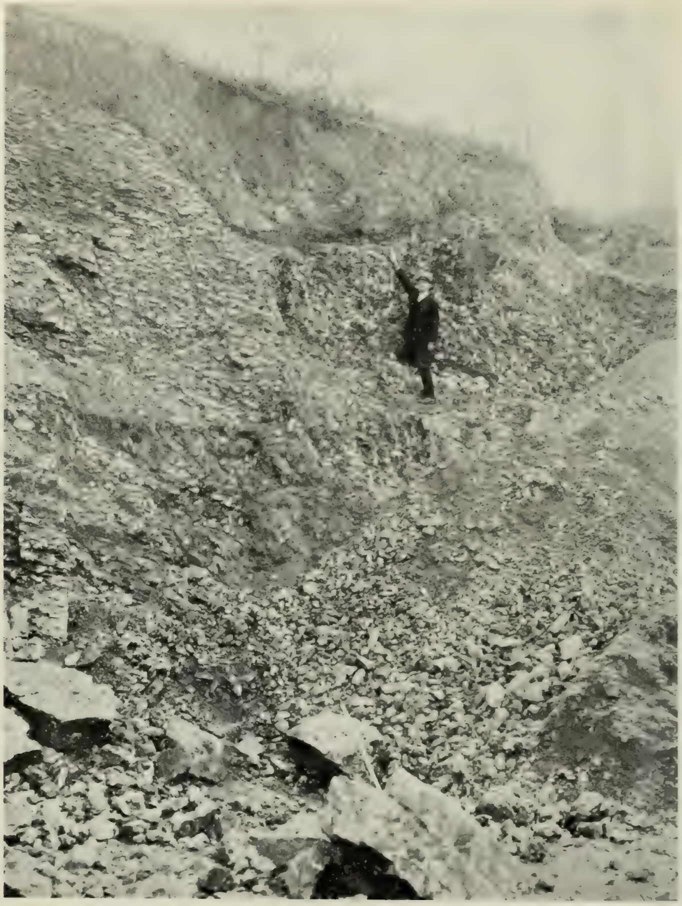


Fig. 1.—Diabase dike exposed in open cut on the American Rutile Company's property at Roseland. See also Pl. XXIV, fig. 1.

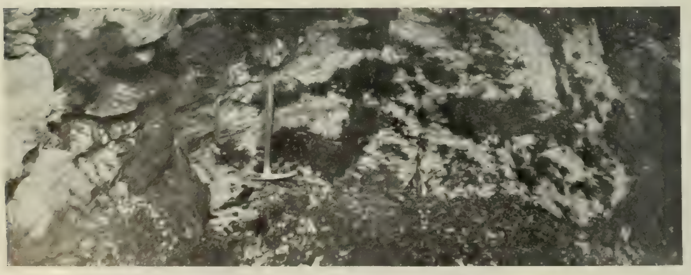


Fig. 2. Exposure of typical hornblende facies of syenite (tonalose). American Rutile Company's quarries at Roseland.

DIABASE DIKE AND HORNBLENDE SYENITE.

section of the rock studied under the microscope shows a uralitic basalt of fine, even-granular texture, composed of the principal minerals basic plagioclase feldspar (near labradorite), much fibrous uralite derived from augite, some biotite, and considerable titaniferous magnetite or ilmenite largely altered to leucoxene. The alteration of augite to uralite has been accompanied by the production of minute grains of black iron oxide.

About half a mile northeast of the above dike a similar rock (Spec. 10) is observed cutting gabbro. It is a fine-grained, bluish-green rock much broken by closely spaced joints along which weathering has progressed. Microscopic study of a thin section shows the rock to be identical with that of the dike (Spec. 11) described above, except that it is slightly finer grained, more altered with mashing of the feldspars shown, and the production of calcite and some epidote.

A diabase dike averaging 25 feet wide and striking approximately N. 80° E. intersects the mass of gabbro (page 95) exposed in the county road about 100 yards south of Roseland Post-office. The line of contact between the two rocks is sharply defined, the diabase following quite closely the jointing in the gabbro (Pl. XXII, figs. 1 and 2). The diabase is also cut by joints but they are independent of those in the gabbro and have a slightly different direction. It is a fine-grained, massive, dark gray rock. Irregular phenocrysts of feldspar are noted in places. Graphite and pyrrhotite (?) in minute grains are sparingly present. The rock is slightly coarser in texture than the dike exposed in the south quarries of the American Rutile Company, described on page 168. Under the microscope a thin section shows a fine-grained rock of diabasic texture, although the lath-shaped outlines are apparent, the feldspar substance is considerably obscured by alteration products. Augite is partly altered to fibrous blue-green hornblende (uralite) and brown biotite. Much titaniferous magnetite or ilmenite is present partly altered to leucoxene. The feldspars are frequently grouped in individual areas which impart a porphyritic appearance to the rock both in the thin section and hand specimen.

MINING AND MILLING OPERATIONS.

The ore is mined from open side-hill cuts, in the bluffs along the east side of the river, which range in height from 20 to 50 feet. In the larger cuts the work is carried on in benches. Hand drills are used, and after blasting the ore down, it is shoveled into a small bin from which it is trammed to the mill. The rock is cut by numerous intersecting fractures and joints which break the ore into fairly small blocks and thus increase the ease of quarrying. The rock is weathered to a considerable depth below the surface, 15 to 20 feet in some places, and the early mining was largely limited to the altered material, because of the lower cost of mining and milling. The weathered zone is very irregular in depth and large masses of unaltered rock occur within the decayed material which sometimes require blasting to break down. These residual masses apparently contain a larger percentage of blue quartz than the average amount contained in the syenite exposed in the quarries. A general view of the surface plant and quarries of the American Rutile Company is shown in Pl. XXVI, fig. 1.

The ore is conveyed to the mill built in 1902, in hand cars, where it is dumped into a second car run on an incline track. This car is raised by a steam hoist to the ore bin at the top of the mill building (Pl. XXV, fig. 1) where the ore, after passing over a grizzly, goes to a Blake crusher. From the crusher the ore falls into a bin and then passes through automatic feeders to the stamps, of which there are 10 weighing 750 pounds each. The mill has been constructed so that another battery of 10 stamps can be added when the demand for the product is sufficient to warrant the increase in production.

In the stamp battery the ore is reduced to pass a 30-mesh screen and then goes to a Brown classifier from which it is delivered to 3 Wilfley tables, each 16 feet long by 5 feet wide. On the tables the pulp is separated into three divisions; concentrates, middlings, and tails. The tails are usually allowed to flow into the river, but in milling ore that is free from quartz and hornblende (feldspar facies of the syenite), the tails consist practically of all feldspar, which in some cases has been saved and sold to manufacturers of porcelain and pottery.

The chemical composition of the tails is shown in the subjoined analyses furnished by courtesy of Mr. W. M. Slater, President American Rutile Company.

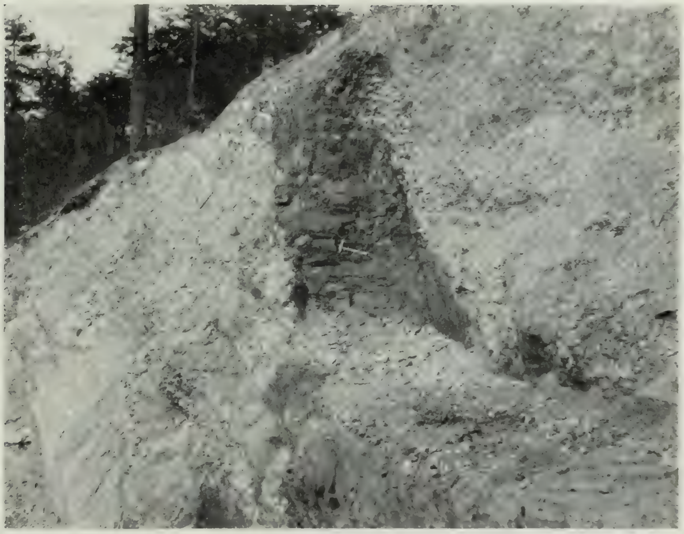


Fig. 1.—Diabase dike cutting syenite in American Rutile Company's quarries at Roseland. See also Pl. XXIII, fig. 1.

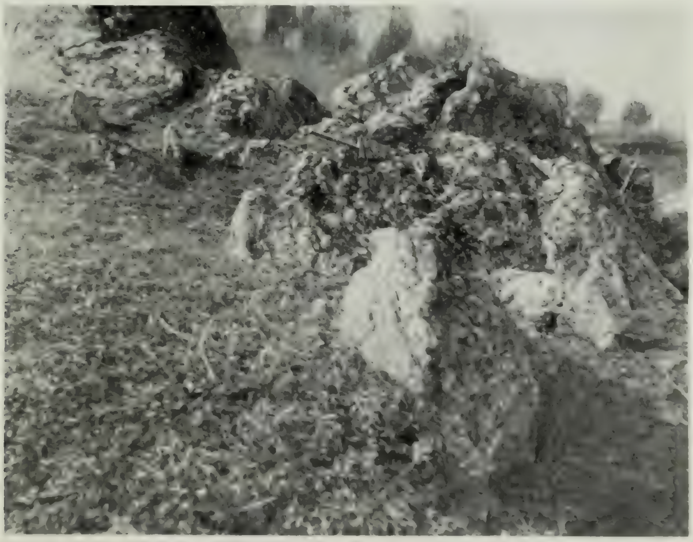


Fig. 2.—Outcrop of feldspathic facies of syenite containing scattered grains of rutile, 0.5 mile north of Bryant.

DIABASE DIKE AND OUTCROP OF SYENITE.

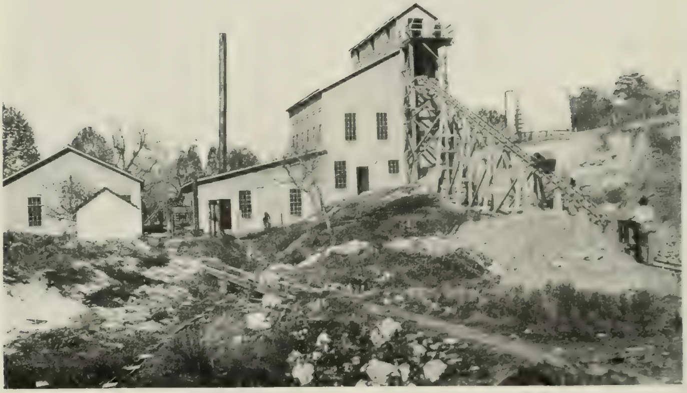


Fig. 1.—Mill and surface plant of the American Rutile Company, Roseland.

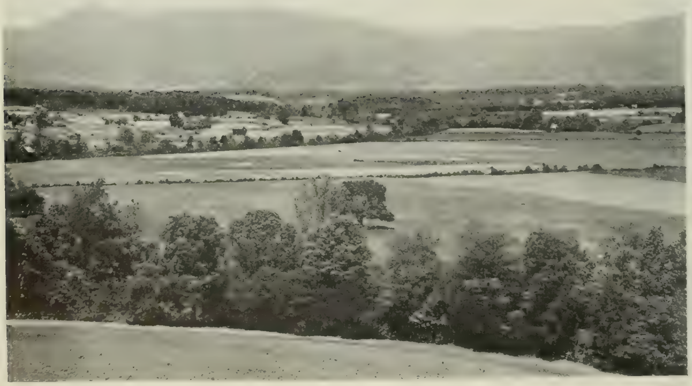


Fig. 2.—View of Piney River valley with the Blue Ridge shown in the background.

RUTILE MILL AND PLANT, AND PINEY RIVER VALLEY.

Analyses of tailings from American Rutile Company's ore.
(U. S. Dept. of Agriculture, Bureau of Chemistry, Division of Tests.)

	I	II
SiO_2	59.10	60.88
Al_2O_3	19.85	24.75
Fe_2O_3	0.77	0.25
FeO	1.88	.....
MgO	1.74	Trace
CaO	4.99	4.78
Na_2O	4.30	4.58
K_2O	2.74	2.25
H_2O-	0.10	0.37
H_2O+	0.75	0.74
TiO_2	3.68	1.60
P_2O_5	0.21	0.45
MnO	0.02	.....
Total	100.13	100.26

Expressed in terms of standard minerals these analyses correspond to the following calculated mineral composition:

	I	II
Quartz	12.12	16.68
Orthoclase	16.12	13.34
Albite	36.15	38.78
Anorthite	23.91	20.57
Corundum	1.02	7.24
Hypersthene	4.30	.....
Magnetite	1.16	.....
Ilmenite	1.52	.....
Hematite	.....	0.25
Rutile	2.88	1.60
Apatite	0.34	1.24
H_2O	0.85	1.11
Total	100.37	100.81

The analyses differ chiefly in the percentage amounts of alumina and iron oxide, a difference readily accounted for by assuming the presence of hornblende in I and its absence from II. They suggest tailings corresponding in mineral composition to the hornblendic (I) and feldspathic (II) facies of the syenite, which becomes apparent when compared with the analyses on page 76.

At present the middlings are returned to the battery and fed with the ore from the crusher. The concentrates, which consist of rutile with small amounts of ilmenite and silicate minerals, are dried, passed through a Wetherill magnetic separator which removes ilmenite and any pyrite present, and packed in heavy double sacks of 200 pounds each for shipment. Two grades of rutile are marketed, designated as "A" grade which averages from 90 to 95 per cent rutile (TiO_2), and "B" grade which averages between 85 and 90 per cent. The rutile for use in the ceramic industries is further pulverized in Sturtevant emery rollers, and packed in casks for shipment. The general character and purity of the rutile are described and indicated in the analyses on pages 172-173 and 193-196.

The power for the mill is furnished by a 55-horse-power slide-valve engine and a 70-horse-power boiler. The mill obtains an abundant water supply from Tye River, the water being taken from the river a few hundred yards above the mill and brought down by gravity.

COMPOSITION OF RUTILE CONCENTRATES.

Through the courtesy of Mr. W. M. Slater, President of the American Rutile Company, there are given below in tabular form 26 analyses (including titanium, metallic iron, and in a few cases silica) of rutile concentrates produced by the company. These analyses afford a good general idea of the composition of the rutile concentrates as regards the chief constituents, titania and iron. Arrangement of the analyses in the table is in the order of titanium content.

With respect to treatment, the analyses fall into two classes: (1) Those made on samples drawn from concentrates that were treated by magnetic machines, and (2) those made on samples drawn from concentrates that were not treated by magnetic machines. The difference in treatment accounts chiefly for the difference in titania and iron contents, the analyses showing low titania and high iron represent concentrates not treated magnetically.

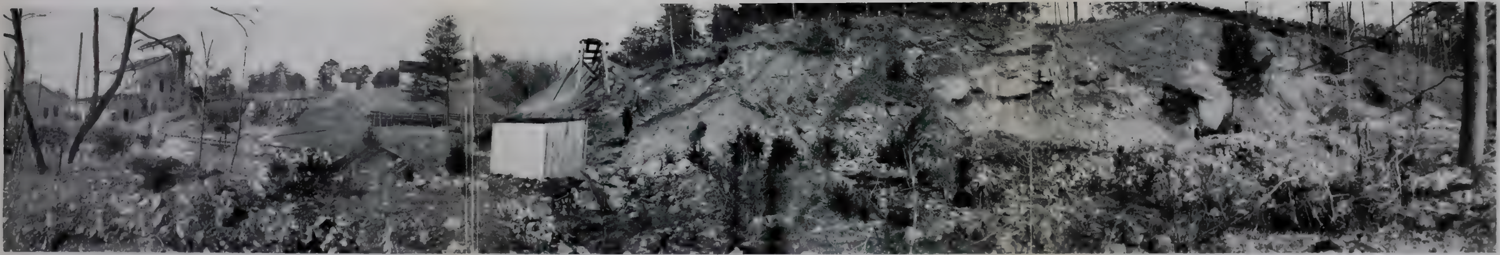


Fig. 1.--General view of surface plant and quarries of the American Rutile Company, at Roseland. Photographed by Frank L. Hess.

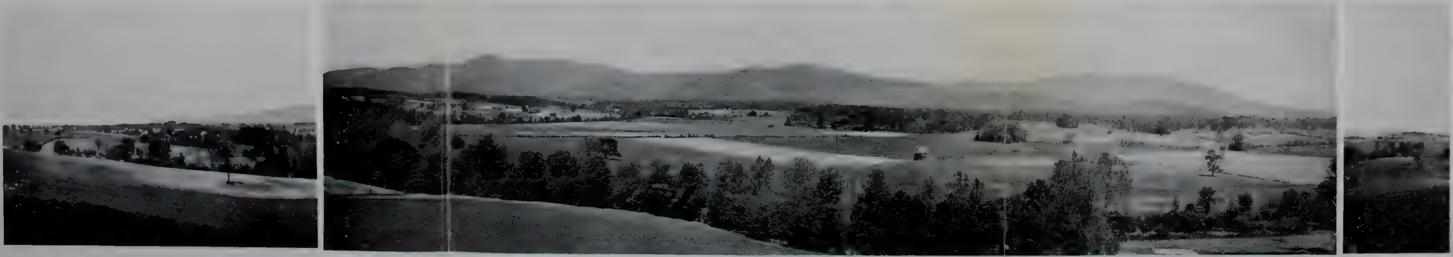


Fig. 2.—General view from the southeast showing the lowland belt of rutile-bearing rocks in the foreground and the Blue Ridge beyond.

Commercial analyses (partial) of rutile concentrates from the American Rutile Company's property.

No.	TiO_2	Fe	SiO_2	Analyst
1	99.22	0.44	....	Waller and Renaud, New York City.
2	98.60	0.40	1.20	General Electric Company's laboratory, Schenectady, N. Y.
3	98.42	0.48	....	Waller and Renaud, New York City.
4	97.54	1.17	....	Ricketts and Banks, New York City.
5	96.50	0.42	0.77	Waller and Renaud, New York City.
6	95.18	1.28	....	Ledoux and Company, New York City.
7	94.65	2.15	....	Simonds and Wainright, New York City.
8	94.47	2.76	0.51	Waller and Renaud, New York City.
9	94.34	4.05	....	Waller and Renaud, New York City.
10	94.12	1.58	....	Waller and Renaud, New York City.
11	93.22	2.26	....	Ledoux and Company, New York City.
12	93.14	4.40	....	Waller and Renaud, New York City.
13	92.94	5.46	....	Waller and Renaud, New York City.
14	91.24	8.02	....	Waller and Renaud, New York City.
15	90.58	5.82	....	Waller and Renaud, New York City.
16	90.10	5.01	1.95	Simonds and Wainright, New York City.
17	89.91	3.46	....	Ledoux and Company, New York City.
18	89.85	8.85	....	Waller and Renaud, New York City.
19	89.30	7.33	0.70	Waller and Renaud, New York City.
20	89.08	2.99	....	Ledoux and Company, New York City.
21	88.73	7.06	....	Waller and Renaud, New York City.
22	88.08	9.45	....	Waller and Renaud, New York City.
23	87.16	7.33	0.44	Waller and Renaud, New York City.
24	86.18	8.24	....	Ledoux and Company, New York City.
25	85.90	9.60	....	Ledoux and Company, New York City.
26	85.60	10.92	....	Waller and Renaud, New York City.

GENERAL ELECTRIC COMPANY'S MINE.

GENERAL STATEMENT.

During the latter part of 1907 the General Electric Company began prospecting for rutile the nelsonite bodies on the Warwick tract, located on Piney River about 1.5 miles northeast of Rose's Mill, 7 miles northwest of Tye River station on the Southern Railway, and 3.5 miles south of Roseland. A number of nelsonite bodies in this vicinity have been opened in prospecting for apatite and rutile, but the most extensive development work has been on two of the nelsonite bodies that outcrop on the Warwick

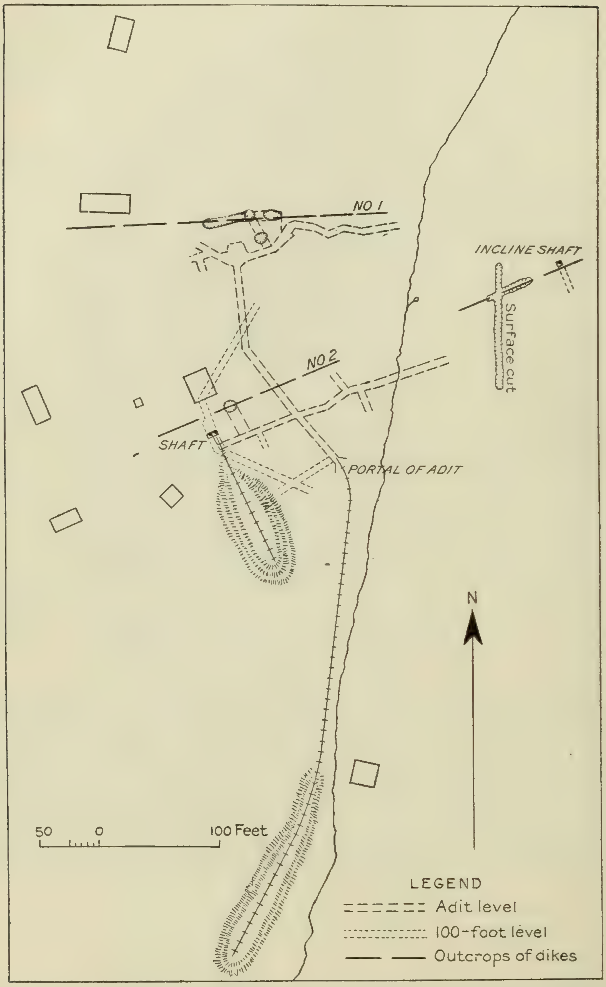


Fig. 12.—Map of surface and underground workings of the General Electric Company's mine, showing outcrops of nelsonite dikes. (Adopted from maps by R. H. Thayer.)

tract about 1.5 miles northeast of Rose's Mill. Here, while prospecting for rutile and mining the rutile-bearing portions of the nelsonite, the General Electric Company exposed the two dikes to a vertical depth of 100 feet and for a distance of several hundred feet along their strike.

A map of the surface plant showing the location of the nelsonite outcrops and their relation to the underground workings is given in fig. 12 on page 174. A historical summary of the mining developments by the General Electric Company on the above property is given on page 50.

MINING DEVELOPMENTS.

The mine formerly worked by the General Electric Company, located on the Warwick tract 1.5 miles northwest of Rose's Mill, lies on the north side of Piney River and near the top of one of the hills or bluffs that outline the river valley and slope steeply down to the lowlands.

The development work was confined to two nelsonite dikes; one of which, known as No. 1 vein, runs nearly east and west, while the other, called No. 2 vein, has a strike of N. 71° E., and both dip in a southerly direction at an angle of about 50 degrees. Map, fig. 12, of the property shows the location of the surface plant and outcrops and their relations to the underground workings. The surface outcrops of the nelsonite dikes, as proved by trenching, are indicated on the map by heavy broken lines.

The development work comprises several hundred feet of tunneling, including drifts, and two shafts, the deeper of which was sunk to a depth of 100 feet. Detailed description follows: An adit level was driven from a deep ravine, in a northwesterly direction under the hill, cutting the two nelsonite bodies at depths of about 30 and 40 feet, respectively. Drives were then opened in both directions along the strike of the nelsonite bodies. A vertical shaft started in the hanging-wall of No. 2 vein was sunk to a depth of 100 feet, cutting through the nelsonite dike between the surface and the adit level, which is 39 feet below the collar of the shaft. The adit was connected with the shaft by a cross-cut, and at the bottom of the shaft cross-cuts were driven to cut the two nelsonite dikes which are about 150 feet apart at this point. On the map, fig. 12, the adit level is shown by broken lines and the 100-foot level by dotted lines.

The rutile-bearing portions of these dikes were mined by stoping and the ore hoisted through the shaft in steel buckets or run out through the adit level in mine cars. In stoping several raises on both dikes were carried through to the surface; these openings are shown on the map, fig. 12. The nelsonite dikes are cut by numerous intersecting joints which cause the rock to break readily into small angular blocks and facilitate mining.

In the summer of 1909 an incline shaft was started on the outcrop of No. 2 vein at a point about 320 feet northeast of the vertical shaft and a drive was extended from this to connect with the one running east from the adit, but this work had not been completed at the time of examination of the property.

The ore was roughly sorted by hand and shipped to Allentown, Pennsylvania, for further concentration and separation of the rutile. The mine was closed down during the winter of 1909 and since then no work has been done on the property.

AREAL GEOLOGY.

Introductory Statement.

Because of the depth of residual rock decay almost nothing of the geological relations of the rocks could be observed on the surface, except where openings had recently been made. Before development work was commenced, the numerous pieces of nelsonite float, honeycombed by the removal of apatite through solution and found littering the surface, furnished the only surface indications of the presence of nelsonite bodies.

Of the two nelsonite bodies explored, one has a strike at the surface of N. 71° E., while the other runs nearly east and west, but both dip toward the south at an angle of about 50°. The first of these was traced by means of trenches placed approximately 50 feet apart, for a distance of more than 1,000 feet. The outcrop, however, is not continuous, for just east of the shaft it is interrupted for a distance of probably 200 feet by a gabbro dike that cuts diagonally across it, and farther east a section of the nelsonite body appears to be faulted approximately 30 feet toward the south. The gabbro does not outcrop at the surface but in the long trench shown on the west side of the map, fig. 12; it could be recognized by the residual decay and the large percentage of graphite present. The gabbro at this point has a width of 70 feet and the nelsonite body, which here is only 3 inches wide, lies approximately on the northern contact with the syenite. The prospecting was not sufficiently extensive to determine definitely that the displacement mentioned above was due to faulting, and it is possible that the nelsonite body pinches out and is replaced by parallel bodies with slight offset in strike, but it appears more likely that faulting is the true explanation for the section of nelsonite that is out of alignment with the rest of the dike, which is very much broken and the outcrop where exposed very irregular.

The nelsonite dike varies in width from 4 feet to 3 inches and in one trench two parallel dikes were exposed 8 feet apart, having a width of 6 and

8 inches, respectively. In some places the dike is composed of ilmenite nelsonite and at others of rutile nelsonite. In one of the exposures of rutile nelsonite the dike was composed in places almost exclusively of apatite.

Although this dike was carefully explored by surface cuts for a distance of slightly more than 1,000 feet it is not improbable that it extends a much greater distance, for with some minor interruptions it may be traced northeast along the direction of strike by means of much float and a few exposures, for a distance of 1.25 miles. Most of the float, however, is ilmenite nelsonite and not the rutile variety.

The second nelsonite dike developed by the underground operations of the company was traced on the surface in an east and west direction for a distance of only 200 or 300 feet. If it continues along the same course far enough east before pinching out, it intersects the larger dike, but exploration was not extended in this direction far enough to determine this point. Passing west along the strike of the dike, it apparently separates into several smaller stringers before disappearing.

A surface pit on the outcrop, 180 feet north of the shaft (map, fig. 12), exposed some of these stringers of rutile nelsonite. The structural relations of the nelsonite to the other rocks found in the opening are shown in the sketch, fig. 13. The rocks are cut by parallel joint-planes along

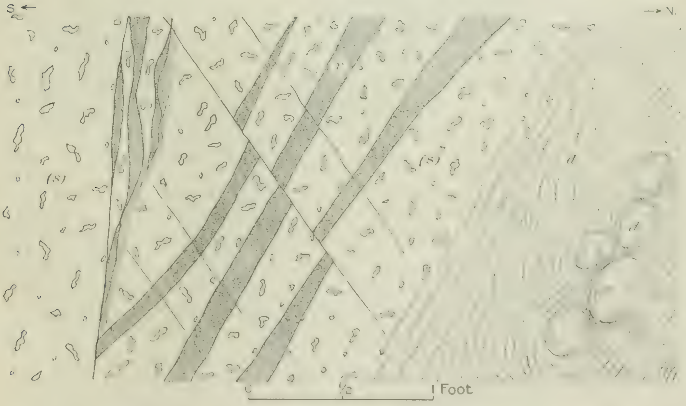


Fig. 13.—Sketch in face of surface cut on dike No. 1, General Electric Company's mine, showing fingering out of nelsonite dike. (*d*) Weathered diabase, (*r*) rutile nelsonite, (*s*) syenite.

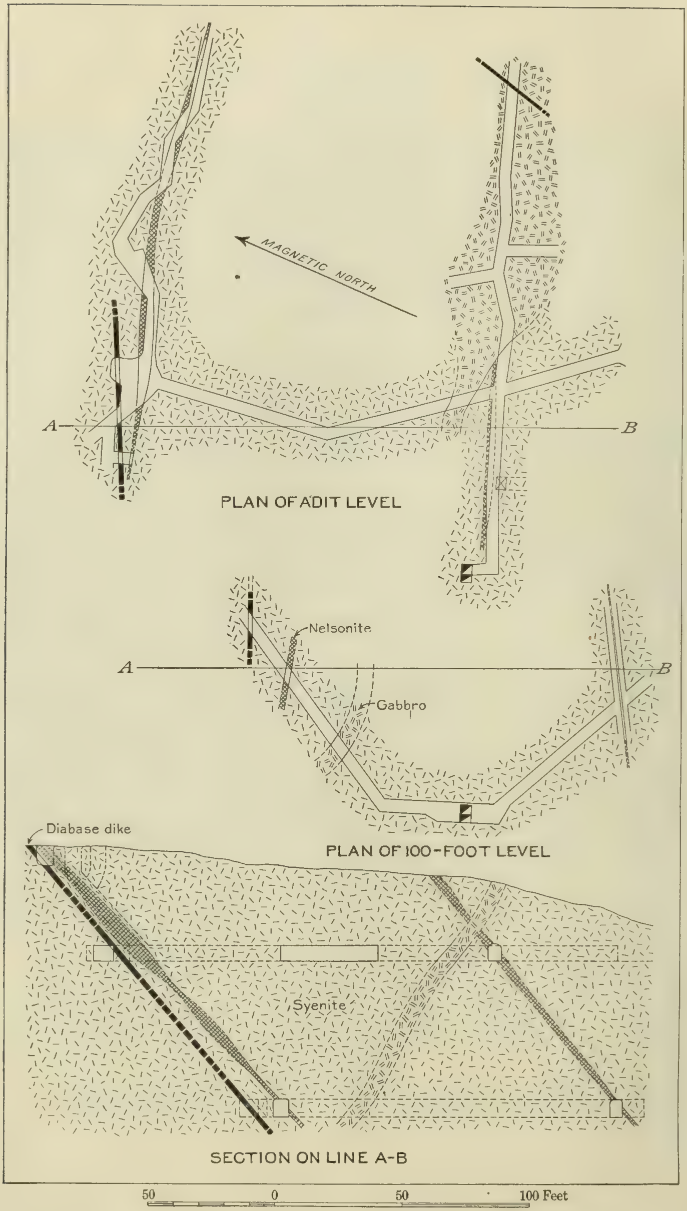


Fig. 14.—Plans of adit and 100-foot levels, and vertical cross-section, in the General Electric Company's mine, Nelson County.

which slight faulting has taken place. The red clay exposed on the north or foot-wall side of the nelsonite stringers is due to the disintegration of a diabase dike that apparently parallels the nelsonite dike in both strike and dip. A few boulders of undecomposed rock, included in the residual decay, indicate its original character and the same dike was cut on both the adit and the 100-foot levels where the rock was perfectly fresh.

While lack of outcrops and depth of residual rock decay precluded detailed geological mapping on the surface, the underground workings were sufficiently extensive to expose the structural relations of nearly all rock types found in the district. Geological maps of the adit and 100-foot levels together with a vertical cross-section showing the geological structure are given in fig. 14.

As indicated in fig. 14 the order of rock differentiation appears to be slightly different here from that noted in other localities in the district, as the gabbro cuts the nelsonite and is therefore younger instead of older as elsewhere observed. The probable order of differentiation then for this locality is as follows: (1) Syenite, (2) nelsonite, (3) gabbro, and (4) diabase. Many facts, however, indicate that (1) and (2) and perhaps (3) were essentially contemporaneous in formation.

Syenite.

The syenite exposed in the different parts of the General Electric Company's mine varies much in mineral composition and structure. Feldspar, usually white in color, is the dominant mineral; blue quartz, always present, ranges from almost nothing up to about 10 per cent of the rock mass; pyroxene and its alteration product hornblende, occur locally in quantity but elsewhere are only sparingly present or entirely absent; rutile and ilmenite are usually to be found in small disseminated grains, and in places graphite is a prominent constituent. The sulphides, pyrite and pyrrhotite, are noticeable in places but were in appreciable quantity only near the nelsonite bodies.

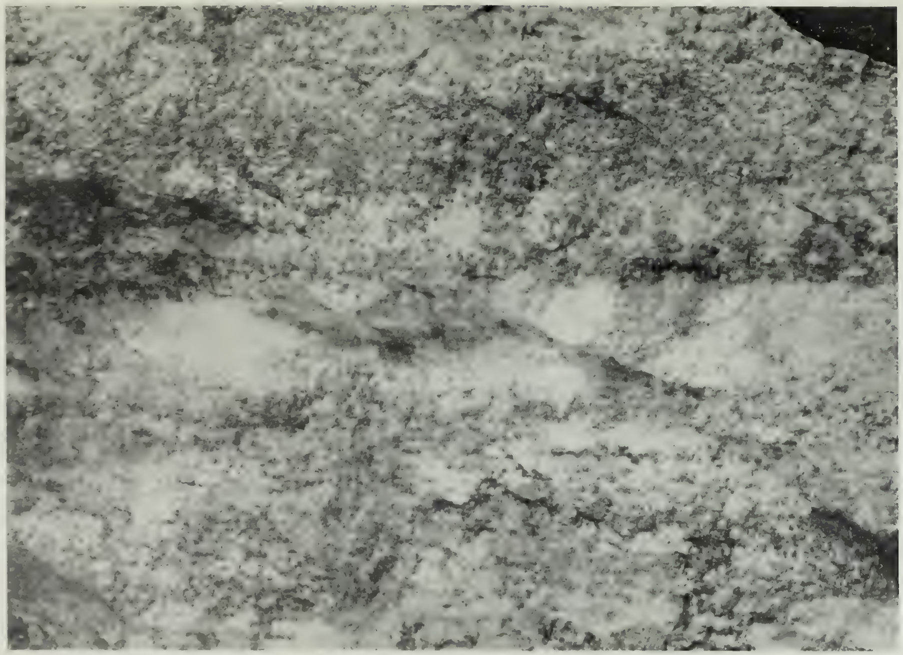
The syenite plainly shows the effects of intense but very unequal dynamic metamorphism in different places, there being no apparent uniformity in distribution of the results, and the cause for such marked irregularity within so localized a section is equally difficult of explanation. In places the rock has been mashed into a strongly foliated and typical gneiss, while in others the development of foliated structure is less apparent but evidence of recrystallization is plainly shown. (See Pl. X, fig. 1.)

DETAILED DESCRIPTION OF OCCURRENCES.

On the adit level the syenite is badly decomposed except near the north end of the workings where there is a greater depth below the surface. Near the portal and between the two nelsonite bodies the syenite is gneissic in structure, the feldspars are extensively kaolinized, and the altered rock is discolored by liberated iron oxide. The iron stain is especially noticeable near the entrance to the adit.

The syenite (Spec. 149) exposed in the face of the east drive from the north end of the adit contains much graphite. The nelsonite at this point is narrow and of the ilmenite variety. The syenite, composed chiefly of white feldspar with some blue quartz in grains up to 1.5 cm. in diameter, is of interest because of the numerous flakes of graphite, averaging about 2 mm. in diameter, that are distributed through both feldspar and quartz, though more plentiful in the former. The graphite is arranged in parallel flakes which impart a gneissic appearance to the rock. (Pl. XXVII.) Some pyrite partly secondary, and a little sericite resulting from the alteration of feldspar were noted. Microscopically a thin section of the rock shows, in addition to these minerals, several small pieces of brown rutile, prismatic inclusions of apatite, and some secondary epidote. Pyrite and graphite are frequently associated in irregular masses, stringers, and fine particles, possibly subsequently introduced into the rock. The thin section of Spec. 148, which indicates mashing of the feldspars from dynamic effects (Pl. X, fig. 1), shows the development of some garnet (Pl. XXVIII, fig. 2).

In the short cross-cut driven south from the west end of this drive the nelsonite pinches to a narrow stringer. The syenite (Spec. 147) is essentially the same as that exposed in the other end of the drive but is slightly more gneissic in structure. The rock is composed chiefly of white feldspar which for the most part is fine-grained. Graphite is distributed through the rock in parallel flakes largely concentrated into bands alternating with those of nearly graphite-free feldspar. A little blue quartz occurs in small lenses parallel to the banding. A little pyrite and pyrrhotite are present, most of the former being closely associated with graphite and probably secondary in origin. The microscope shows additional minerals to be occasional small grains of rutile and ilmenite and needle-like inclusions of rutile, together with the secondary minerals zoisite, epidote, and colorless mica derived from the alteration of feldspar. Both feldspar and quartz exhibit marked effects of crushing from dynamic forces. Plate XXVIII, fig. 1, is a photomicrograph of the thin section, showing graphite.



Specimen of syenite containing much graphite, which imparts a rudely banded appearance to the rock. General Electric Company's mine. Natural size.

SYENITE CONTAINING GRAPHITE.

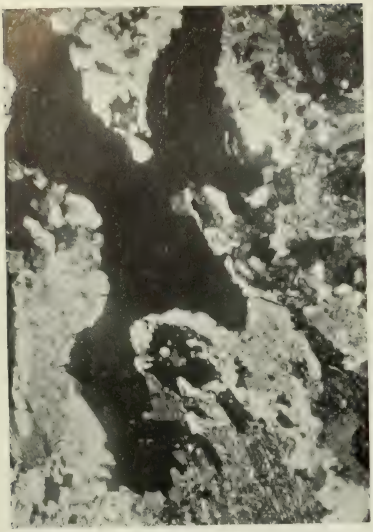


Fig. 1.—Photomicrograph of feldspathic facies of syenite containing graphite. Light areas feldspar partly altered, and a little quartz; dark areas graphite with some pyrite. General Electric Company's mine. Nicols crossed. Enlarged 30 diameters. Specimen No. 147.

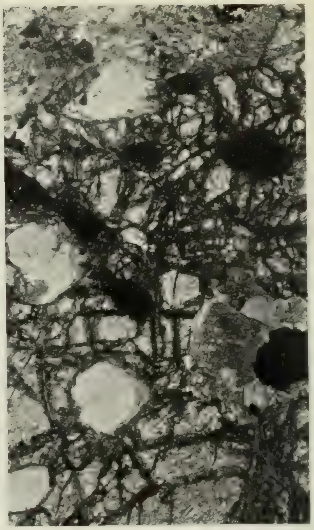


Fig. 2.—Photomicrograph of mashed syenite containing garnet. Fractured areas of high relief are garnet. Other minerals are fibrous hornblende, altered feldspar, and ilmenite. General Electric Company's mine. Nicols crossed. Enlarged 50 diameters. Specimen No. 148.

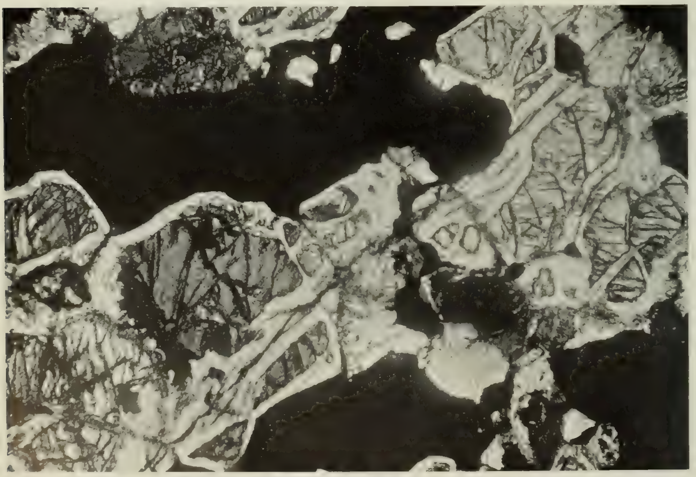


Fig. 3.—Photomicrograph of gabbro-nelsonite, 1 mile east of Rose Union, showing alteration of hypersthene to hornblende (uralite). Much ilmenite and a little apatite are also shown. Nicols crossed. Enlarged 30 diameters. Specimen No. 136.

PHOTOMICROGRAPHS OF SYENITE AND GABBRO-NELSONITE.

In the face of the drive 20 feet northeast of this point and extending about 40 feet east very gneissic syenite is exposed consisting of fine-grained white feldspar, blue quartz drawn out into long, broken lenses, and secondary hornblende in narrow parallel lines. Ilmenite and rutile are scattered through the rock; also a little graphite, light brown biotite, and the sulphides, pyrite and pyrrhotite. Microscopically the rock is a hornblende syenite-gneiss showing marked evidence of crushing and the development of some garnets which are much fractured. As in the specimens described above pyrite and graphite are usually intimately associated.

On the 100-foot level the syenite is unaltered. In the cross-cut running southeast from the shaft it is composed almost entirely of white feldspar with scattered grains of blue quartz, and a few small grains of ilmenite and rutile with little if any ferromagnesian minerals present until close to the nelsonite body.

The syenite forming the foot-wall of the nelsonite body (vein No. 2) on the 100-foot level is composed almost exclusively of feldspar and blue quartz, but on the hanging wall side it contains much pyroxene which is largely altered to hornblende. Close to the hanging wall side of the nelsonite (see fig. 16) the syenite contains much pyrrhotite in bright, irregular anhedra, ranging up to 1 cm. or more in size, strung out in broken lines parallel to the nelsonite body. Pyrrhotite rapidly decreases in quantity a short distance from the contact, while pyroxene and its alteration product hornblende increase. A few scattered grains of ilmenite are noted. The feldspar frequently shows warped cleavage faces 3 to 4 cm. across.

About 20 feet northeast from the face just described the drive passes through a light gray syenite (Spec. 142) composed almost entirely of feldspar. The feldspar is light pinkish-gray and sometimes shows warped cleavage faces on which perthitic intergrowths may be distinguished with the aid of a pocket lens, and some of them exhibit fine multiple twinning. The large feldspar individuals show granulation near their boundaries and grade into mosaics of the fine-grained mineral of similar color and appearance. The rock also contains a few small lenses of dark blue quartz and a little hornblende, ilmenite, and pyrrhotite, but these combined make up a very small percentage of the rock mass. The pyrrhotite is developed in grains about 2 cm. in size and is usually noticed close to the quartz but not included in it. The microscope shows minor accessory minerals to be rutile and apatite as inclusions, minute areas of colorless mica derived from feldspar alteration, with the usual evidence of crushing manifested in the principal minerals. An analysis (IV) of this rock is given in the table on page 76.

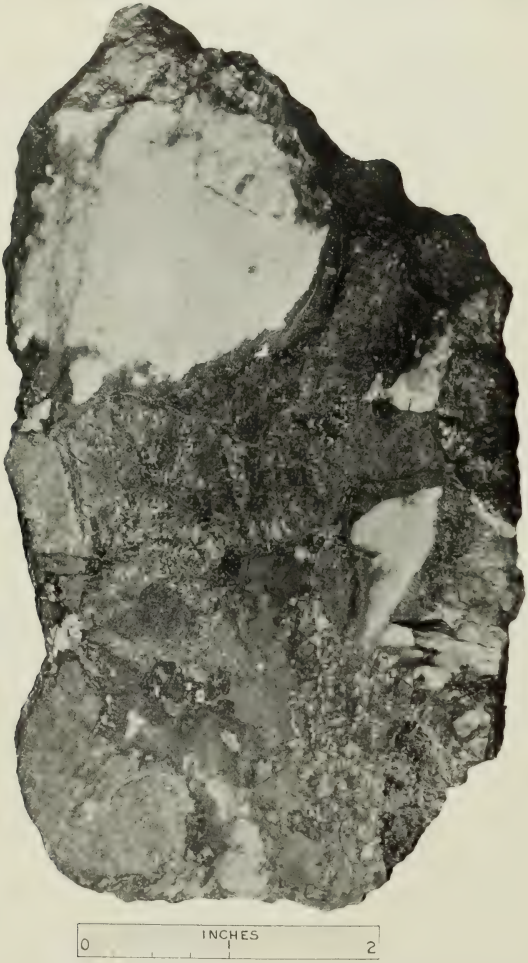
In the same vicinity another specimen (143) of light gray syenite was obtained that shows evidence of alteration. It consists of white feldspar cut by intersecting fractures running in different directions and along these the feldspar appears to have undergone some alteration accompanied by the production of sericite. The lines of alteration are gray in color and cut the large, warped cleavage faces as well as the fine-grained feldspar. In places where the lines intersect, considerable areas of the gray may be seen. A little dark blue quartz and a few grains of rutile and ilmenite are distributed through the rock. Microscopically a thin section of the rock shows the feldspar to contain abundant inclusions, and is altered on the surface to light-colored mica, zoisite, and epidote. Crushing is pronounced in fine-grained mosaics of quartz and feldspar. Quartz ranges from very small granulated grains to large anhedra filled with rutile needles, and exhibiting marked wavy extinction.

In the northeast face of the drive, where the nelsonite completely pinches out, the syenite is similar to the hornblende variety at the other end of the drive. The white feldspar is mostly in small anhedra 2 to 3 mm. in size which sometimes display fine multiple twinning. The small size of the feldspar grains is evidently due to crushing, for many of the cleavage faces are warped into curved surfaces. Pyroxene and its alteration product hornblende occur together in large connecting masses 5 to 10 cm. across.

In Pl. VII is shown a photograph (natural size) of a polished specimen of the rock and the sketch (fig. 15) made partly from the same specimen, illustrates the formation of the secondary hornblende. The unaltered pyroxene (hypersthene) is dark brown to bronze in color and forms the centers of the larger masses of hornblende. It is surrounded by a zone of dark green hornblende (uralite), usually fibrous, with silky lustre, which extends out into the feldspar along cleavage planes and fractures, giving the irregular outlines noted in the photograph.

The alteration is probably due to the circulation of solutions along almost microscopic fractures, since most of the hornblende masses are connected by them. The feldspar has evidently furnished part of the material entering into the formation of the hornblende, for where the fractures pass through the feldspar, hornblende has been developed and they are marked by dark green lines ranging up to 2 mm. in width, but where the fractures cross the blue quartz no alteration has taken place and they are almost invisible.

Small grains of ilmenite and rutile are scattered through the rock together with the sulphides, pyrite and pyrrhotite, the former being partly



Polished specimen of hornblende facies (border) of syenite (tonalose) from the American Rutile Company's quarries at Roseland. Light-colored, nearly white, areas are feldspar containing scattered small grains of blue quartz; dark areas, which make up the bulk of the specimen, are mostly fibrous actinolite (uralite) derived from hypersthene. Unaltered, scattered, irregular areas of hypersthene are plainly visible, especially in the middle and lower half of the specimen. (Collected by Frank L. Hess. Photographed by U. S. Geol. Survey.)

HORNBLENDIC FACIES OF SYENITE.

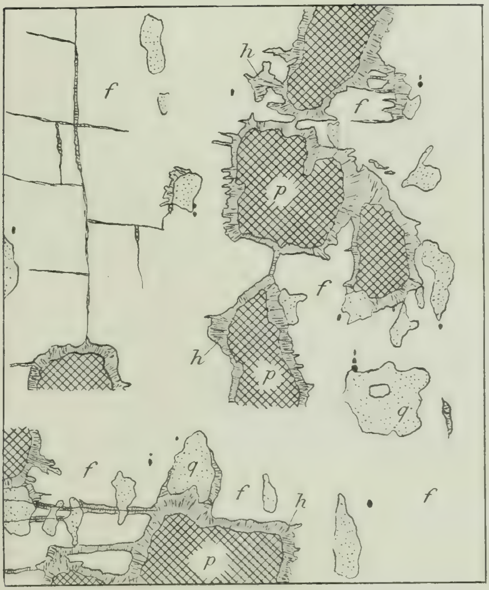


Fig. 15.—Sketch showing alteration of pyroxene to amphibole (uralite). (*f*) Feldspar, (*h*) hornblende, (*p*) pyroxene, (*q*) blue quartz. (See also Pl. VII.)

secondary. In places the ilmenite and rutile are concentrated in larger quantity, when apatite is usually present also. In Pl. XXX is shown a photograph of another polished specimen of the rock containing ilmenite and rutile arranged in irregular stringers associated with granular apatite.

An analysis (I) made of an average sample of the hornblende syenite is given in the table on page 76; also an analysis made of the unaltered pyroxene (hypersthene) is inserted on page 74.

The syenite exposed in the north cross-cut on the 100-foot level presents no unusual features. It is composed for the most part of feldspar and blue quartz, together with rutile, ilmenite, and the ferromagnesian minerals as minor accessory constituents.

Nelsonite.

In the underground workings the nelsonite bodies vary in width from 5 feet down to a fraction of an inch. Normally the rock is an even-granular mixture of ilmenite and apatite, with more or less rutile, a little pyrrhotite, and secondary pyrite. The apatite occurs in rounded grains 1 to 2 mm. in size which often show roughly hexagonal cross-sections, and the ilmenite which is usually dominant surrounds the grains of apatite and fills the interstices between them. Rutile is usually present in small quantity and in places becomes the dominant mineral. In the same dike and within short distances the normal ilmenite nelsonite passes by increase of rutile into the rutile variety of nelsonite in which ilmenite is absent or only sparingly present.

Where the ilmenite is greatly in excess over rutile the nelsonite is remarkably uniform in texture and composition, but where rutile predominates the rock becomes much more variable. In the rutile nelsonite the apatite shows a strong tendency to segregate in the form of lenses or bands of the almost pure granular mineral. The change in composition is not sudden but a gradation from the mass of pure apatite to ordinary nelsonite. Segregations of pure rutile also occur but they are not so numerous as the apatite masses. This segregation of minerals often gives the dike an appearance of imperfect banding or crustification.

Blue quartz is usually a prominent constituent of the rutile nelsonite and sometimes forms an appreciable percentage of the rock mass. It appears to be more closely associated with the rutile than with the apatite and to have crystallized out at about the same time, for both rutile and quartz occur as an interstitial filling binding the grains of apatite together. Where the percentage of apatite is small the individual grains of the mineral, which have the same size and shape as when it is dominant, occur as inclusions in the larger masses of rutile or quartz. Blue quartz is seldom observed megascopically in the ilmenite nelsonite and where present is usually confined to the border portions of the rock near the contact with syenite.

DETAILED DESCRIPTION OF OCCURRENCES.

In the face of the east drive from the north end of the adit level the nelsonite is narrow and of the ilmenite variety. In the short cross-cut driven south from the west end of the drive the nelsonite body pinches to a narrow stringer.

The nelsonite body exposed by the east and west drive (on vein No. 1) carried a high percentage of rutile where it was first cut by the adit, and was completely stoped to the surface for a distance of about 40 feet along the strike. A specimen (215) of the rutile nelsonite is composed of the following minerals named in order of their relative abundance: Rutile, apatite, blue quartz, ilmenite and a little pyrite, probably secondary. The apatite is developed in grains 2 to 3 mm. long and about 1 mm. thick, some of which show roughly hexagonal cross-sections. As most of the apatite grains are oriented in the same direction the rock presents a rudely banded appearance, which may be due to flowage that occurred after the apatite had crystallized but before the rock had completely solidified. The rutile and blue quartz surround the apatite grains and bind them together. Microscopically a thin section of the rock shows rutile, apatite, and ilmenite, with some pyrite, and the usual secondary minerals. No unusual features are observed. An analysis of this rock is given on page 120.

This ore-shoot of rutile nelsonite passed into normal ilmenite nelsonite by gradual increase of ilmenite. Specimens of the ilmenite nelsonite show no blue quartz but seem to contain a much higher percentage of pyrite. A photograph of a polished specimen of this nelsonite is reproduced in Pl. XII, fig. 1.

Thirty feet from the east face of the drive the nelsonite splits and between the two branches a layer of rock occurs 2 to 4 inches thick and intermediate in mineral composition between nelsonite and syenite. The rock (Spec. 150) consists of a fine-grained ground-mass composed of apatite, blue quartz, rutile, ilmenite, biotite, graphite, pyrrhotite, and pyrite, in which are imbedded larger masses of blue quartz and feldspar of irregular outline and ranging up to more than 1 cm. in size. Some of the feldspars show fine multiple twinning. Some chlorite and sericite are noted as alteration products. It is difficult to determine by megascopic examination whether the feldspar and blue quartz present in this rock are the result of inclusions or are due to some process of segregation. Microscopic examination of thin sections of the rock indicates that the silicate minerals are original and were formed by segregation processes. It is therefore intermediate in mineral composition between normal nelsonite and syenite.

In the other nelsonite body (vein No. 2) a rutile ore-shoot about 40 feet wide was encountered between the adit and shaft. This was stoped out to the surface and a winze started down to connect with the 100-foot level. The ore exposed in the winze showed extensive segregation of apatite and rutile into masses of almost pure mineral. A hand specimen

(155) was obtained which showed lenticular segregations of apatite more than 8 cm. in thickness. These lenses are composed of granular apatite with very little impurity except near the border where they grade into nelsonite in which rutile predominates. In the larger masses of apatite (Spec. 154) the only accessory minerals that could be identified megascopically were pyrite and pyrrhotite, a grain of the former being found in the center of an apatite crystal, but the pyrite is largely if not entirely secondary in origin. Microscopically a thin section of the rock (Spec. 154) showed apatite without trace of titanium-bearing minerals or sulphides. A thin section of specimen 155 showed the following minerals: Apatite and rutile, the former greatly predominating, together with accessory pyrite, a few grains of ilmenite partly altered to leucoxene, and an occasional grain of quartz. An analysis of this rock (Spec. 154) is given on page 108.

The nelsonite body is cut by closely spaced joint planes along which much secondary pyrite has been deposited coating the nelsonite, but where the fractures cut segregations of pure apatite scarcely any pyrite is found.

Some blue quartz is present in most of the rutile nelsonite, and it is found concentrated in greater quantity along the contact with the syenite or where there are included masses of the latter in the nelsonite. Along such contacts a few small shreds of light brown mica (biotite) may usually be distinguished. Masses of coarsely crystalline rutile (Spec. 158) occur that are practically free from impurities other than sulphides, but they do not seem to be as numerous as the segregations of apatite. By increase of apatite they grade into the even-granular nelsonite. In Pl. XV a polished specimen of rutile nelsonite is reproduced natural size, showing rudely imperfect banding due to partial segregation of the rutile and apatite. Masses of nearly pure rutile grade into bands of nelsonite in which apatite predominates. The apatite appears to have crystallized first, for the grains are surrounded and held together by rutile, and in places very fine veinlets of the latter penetrate the apatite grains. Some long, narrow stringers or irregular lenses of kaolinized feldspar and blue quartz may be seen on the right side of the plate. Pyrite apparently secondary was the only other mineral that could be identified.

Sketch fig. 16 shows the appearance of the southwest face in the drive along the nelsonite body (Specs. 140A to D) in the 100-foot level. The nelsonite body (vein No. 2) varies from 6 inches to 18 inches in width, is an even-granular rock consisting of 75 to 80 per cent of ilmenite, apatite, and a little pyrrhotite and pyrite. It is cut by many joint planes along

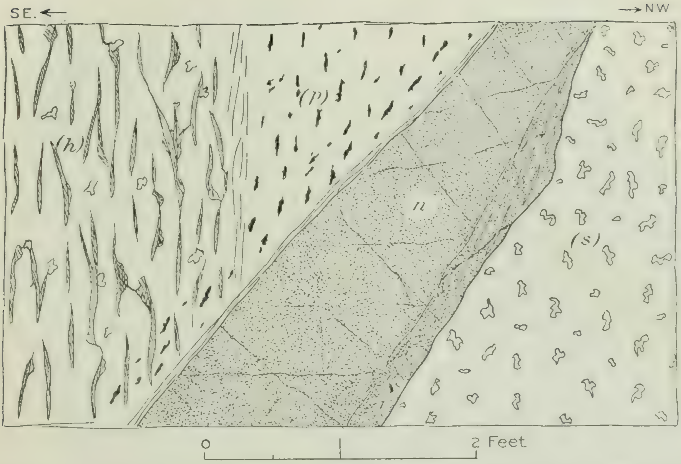


Fig. 16.—Sketch showing nelsonite in face of southwest drive on No. 2 dike, 100-foot level, of the General Electric Company's mine, Nelson County. (*h*) Feldspar, blue quartz, and hornblende, (*n*) nelsonite, (*s*) feldspar and blue quartz, (*p*) feldspar chiefly with streaks of pyrrhotite.

which it breaks readily into angular blocks. On the foot-wall side there is a strip of nelsonite varying in width from 4 or 5 inches down to almost nothing which contains narrow stringers or lenses of feldspar and blue quartz. In places the nelsonite in this strip runs higher in apatite, perhaps as much as 75 per cent, but otherwise it is not different from the main portion of the nelsonite body. The grains of apatite average about 1 mm. in size and often show roughly hexagonal cross-sections; the ilmenite surrounds and fills the interstices between the apatite grains. Passing northeast along the nelsonite body it is found to be irregular in width but uniform in composition, there being no rutile nelsonite exposed such as was found on the level above.

The east and west nelsonite body (vein No. 1), where cut in the cross-cut on the 100-foot level, was 18 inches wide and dipped toward the south 50°, but in a raise started at this point the dike rapidly narrowed and split into a number of stringers similar to those exposed in the surface opening on the same dike. The nelsonite at this point is composed essentially of ilmenite and apatite with little, if any, rutile. A little pyrrhotite and secondary pyrite were also noted.

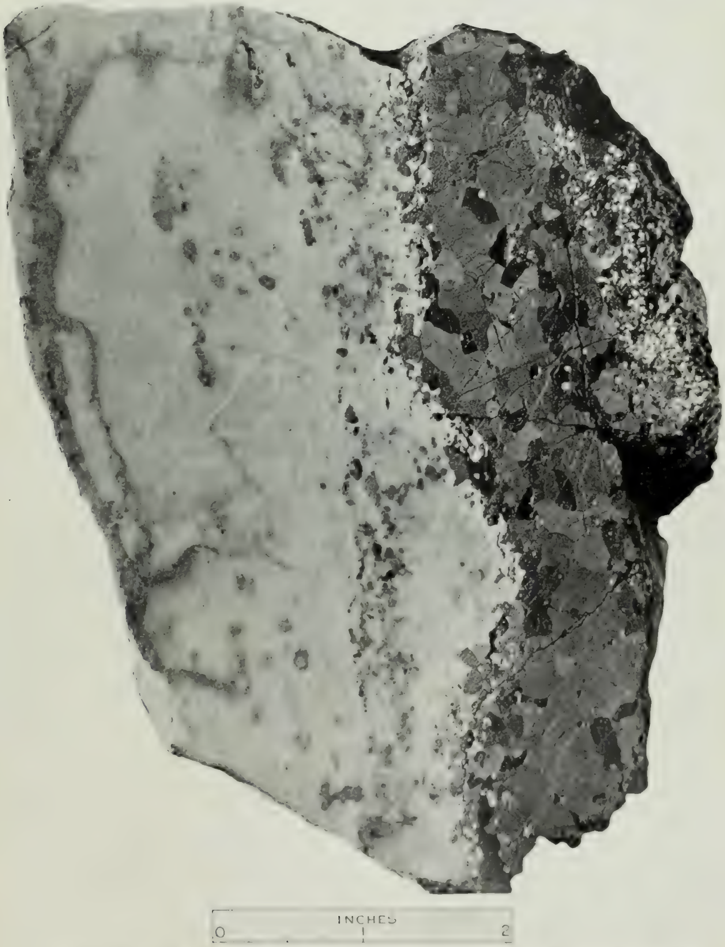
In several places narrow tongues 1 to 3 mm. wide and as much as 2 cm. long extend outward from the nelsonite into the syenite. The nelsonite is uniform in texture and composition except along the contact where there is a band 1 to 4 mm. in width consisting of small flakes of light brown biotite, blue quartz, ilmenite, and occasional grains of apatite. The syenite forming the walls of this stringer is composed of white feldspar with a little blue quartz drawn out into broken lines parallel to the nelsonite, and a few scattered grains of pyrrhotite and ilmenite, the latter being more abundant near the contact. A little pyrite mostly secondary is present in the specimen but is almost entirely confined to the nelsonite.

In places the rutile nelsonite grades into the syenite without definite contacts, which is more noticeable when the dike is narrow and where rutile greatly predominates over apatite.

This gradation is well shown in a polished specimen obtained from one of the nelsonite bodies on the adit level and reproduced in Pl. XXX. In this specimen the boundary between the syenite and nelsonite is very irregular; rutile extends out into the syenite and feldspar into the nelsonite. For a distance of 3 or 4 cm. from the syenite the nelsonite stringer is composed almost entirely of rutile with about 10 per cent of ilmenite in interlocked anhedra averaging 0.5 cm. in size. There are a few scattered grains of apatite most of which are in contact with or wholly inclosed by ilmenite. By increase in apatite the stringer grades laterally into typical nelsonite. There are numerous grains of rutile and ilmenite in the syenite within 3 or 4 cm. of the nelsonite stringer and also occasional grains of apatite. The syenite contains a few small lenses of blue quartz with their longer axis parallel to the nelsonite stringer.

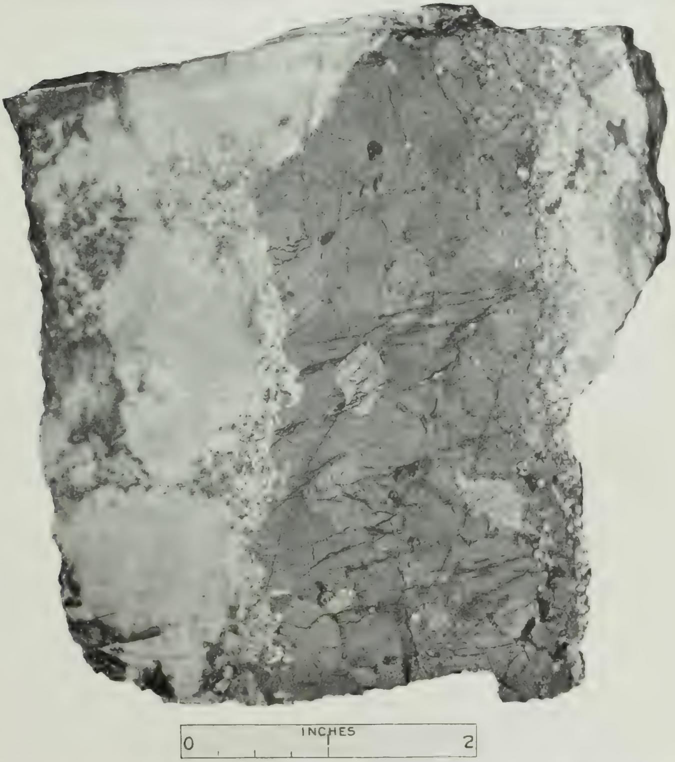
There are numerous cavities in the nelsonite partly filled with ferric hydroxide and smaller cavities in the syenite surrounded by reddish-brown stains. It is believed that these cavities were originally filled with pyrrhotite that has been leached out and in part redeposited below as secondary pyrite. The feldspar of the syenite is kaolinized along fractures and cleavage planes and more extensively along the contact with nelsonite.

Near these rutile-apatite stringers the syenite is sometimes composed of large feldspar individuals 10 cm. or more in size with irregular rounded boundaries, the space between them being filled with rutile, ilmenite, apatite, blue quartz, and smaller grains of feldspar. This occurrence is illustrated by the polished specimens shown in Pls. XXX and XXXI. The large feldspar seen in Pl. XXXII is a light bluish-gray individual of microperthite twinned on the Carlsbad law.



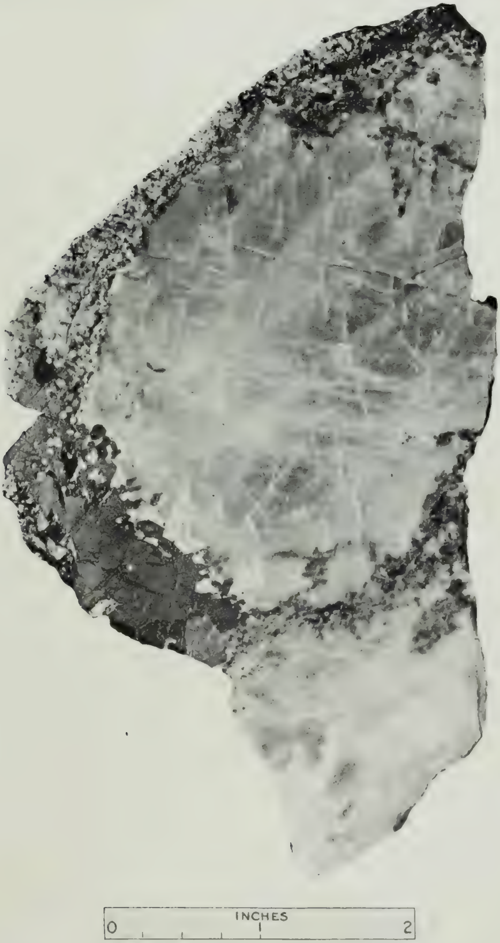
Polished section of a rutile segregation in nelsonite dike from General Electric Company's mine, Nelson County. The syenite on the left, composed essentially of feldspar, shows small eyes of blue quartz, and small grains of rutile. (Collected by Frank L. Hess. Photographed by U. S. Geol. Survey.)

RUTILE SEGREGATION IN NELSONITE.



Polished section of a rutile segregation in nelsonite dike from General Electric Company's mine, Nelson County. The blotched appearance of the rutile (dark band) is due to difference in the orientation of rutile crystals. On each side of the rutile is an irregular band composed chiefly of apatite with some small grains of rutile. The inclosing rock is syenite containing chiefly feldspar (nearly white-grayish masses) and occasional blue quartz. (Collected by Frank L. Hess. Photographed by U. S. Geol. Survey.)

RUTILE SEGREGATION IN NELSONITE.



Polished specimen of a large Carlsbad twin of perthitic orthoclase on border of nelsonite dike. Projection at bottom is country rock (syenite) containing feldspar and some small eyes of blue quartz. Rutile segregations rimming the feldspar twin same as in Pls. XXX and XXXI. (Collected by Frank L. Hess. Photographed by U. S. Geol. Survey.)

CARLSBAD TWIN OF FELDSPAR IN NELSONITE.

Most specimens of nelsonite taken from the adit level disintegrate in the course of a few months on exposure to the atmosphere. This is due to the rapid oxidization of one of the iron sulphides, and is accompanied by the formation of an efflorescence of ferrous sulphate and sometimes by the liberation of free sulphur. The nelsonite from the 100-foot level although containing both pyrrhotite and pyrite does not undergo this rapid oxidation.

The pyrrhotite appears to have been a primary constituent but it is believed that the pyrite is mostly if not entirely secondary in origin and was probably derived in part at least from the pyrrhotite in the rocks near the surface and redeposited below. In the nelsonite close to the surface the sulphides have been almost completely removed by oxidation and solution. The secondary pyrite deposited along joint planes seems to show a preference for the nelsonite, as very little is found in the syenite or even in the segregations of pure apatite occurring in the nelsonite. It is of interest to note that notwithstanding the extensive solution and removal of apatite from the nelsonite near the surface no evidence of secondary apatite redeposited at depth was found in any of the underground workings.

Composition of the apatite.—An analysis of apatite made from one of the segregated masses occurring in the rutile nelsonite at the General Electric Company's mine gave the following results:

Analysis of apatite from General Electric Company's mine, Nelson County.
(WM. M. THORNTON, JR., *Analyst.*)

	Per cent.
CaO	54.37
MgO	0.53
P_2O_5	41.30
F	2.50
Cl	0.10
SiO_2	0.33
TiO_2	0.20
Fe_2O_3	0.61
H_2O	0.19
	100.13
Excess oxygen	1.07
	99.06

As indicated by the analysis the mineral is the fluor-apatite variety, containing a very small amount of chlorine. This is in accord with the nelsonites in general as an examination of the table of analyses of the rocks, on page 147, reveals the fact that the variety of apatite present is a fluor-apatite, in which a variable but minute quantity of chlorine is frequently present. One analysis showed the interesting variety mangan-apatite to be present in the rock.

The Bureau of Standards determined the melting point of the apatite represented by the above analysis to be 1,645° C.

Composition of the rutile.—A specimen of rutile isolated and cleansed from nelsonite at the General Electric Company's mine yielded the following results on analysis:

Analysis of rutile from General Electric Company's mine, Nelson County.

(WM. M. THORNTON, JR., *Analyst.*)

	Per cent.
TiO_2	98.80
FeO	1.68
SiO_2	0.26
V_2O_3	0.20
Cr_2O_3	0.07
SnO_2	None
Cb_2O_5	None
Ta_2O_5	None
	101.01
Specific gravity	4.21

A determination of the melting point of the rutile represented by the analysis above made by the Bureau of Standards gave 1,700° C. The chief interest which attaches to the composition of the nelsonite rutile, shown in the analysis above, as well as that of the syenite rutile (page 194), is the presence of vanadium and chromium in very small but determinable amounts. It is of interest to note in this connection that the ilmenite of the nelsonite (page 191) also shows appreciable small quantities of the same elements. In both minerals, rutile and ilmenite, tantalum and columbium were carefully looked for but were not detected.

Composition of the ilmenite.—The chemical composition of the ilmenite separated from the rock ilmenite nelsonite is shown in the subjoined analysis:

Analysis of ilmenite from the General Electric Company's mine, Nelson County.

(WM. M. THORNTON, JR., *Analyst.*)

	Per cent.
TiO_2	54.44
FeO	40.94
MnO	0.52
Fe_2O_3	4.26
SiO_2	0.34
Cr_2O_3	0.07
V_2O_3	0.29
SnO_2	Trace
Cb_2O_5	None
Ta_2O_5	None
	100.86
Specific gravity	4.713

The melting point of the ilmenite as measured by the Bureau of Standards is 1,390° C.

Gabbro.

A gabbro dike 7 feet wide was cut by the adit at a distance of 60 feet from the portal, where it dipped toward the north at an average angle of 50°. Westward the gabbro cuts the nelsonite body and widens rapidly, so that within 50 feet it has increased to more than 40 feet in width. (See fig. 14). On this level the gabbro is almost completely disintegrated and about the only unaltered mineral constituent is graphite, which occurs uniformly distributed in large quantity. There are numerous lenticular inclusions or stringers of syenite distributed through the gabbro which show much less alteration than the inclosing rock. They are composed chiefly of feldspar with blue quartz drawn out into long, irregular, broken lines and usually contain a few small grains of rutile. Some of them carry much graphite.

One hundred and twenty feet west of the adit the drive passed through a partly decomposed diabase dike 15 inches wide, having a strike of N. 15° E., and a dip of 45° towards the southeast. Just beyond this dike a fairly fresh specimen (148) was obtained from the face of the drive but it is uncertain whether it represents an altered inclusion of syenite or a rock intermediate between it and gabbro. It is a medium-grained, dark gray, gneissic rock composed of feldspar, blue quartz, hornblende, graphite, garnet, and biotite. The flakes of graphite are mostly developed in the feldspar but also occur in the quartz and hornblende. The garnet occurs in irregular pink grains. (See Pl. XXVIII, fig. 2.)

The gabbro was cut again in the north cross-cut on the 100-foot level about 50 feet from the shaft. The dike at this point is 8 feet wide, dips 55° towards the north, and has a strike of S. 76° E. It is a porphyritic rock (Spec. 145) of dark brown color, the irregular phenocrysts of feldspar measuring about 5 mm. in size and imbedded in a ground-mass of blue quartz, feldspar, hornblende, ilmenite, rutile, biotite, graphite, and a little sericite. The rock is quite similar in appearance to the gabbro (Spec. 13) found on the American Rutile Company's property near Roseland. Microscopically a thin section of this rock showed pronounced foliated structure. It is composed of biotite largely altered to brown chlorite, pyroxene altered to fibrous blue-green hornblende, alkalic feldspar, quartz, apatite in large anhedra, ilmenite altered peripherally to leucoxene, zircon (?), and colorless mica. A part of the pyroxene (hypersthene) represents cores rimmed by the secondary fibrous hornblende. The quartz is granulated and exhibits marked wavy extinction.

An analysis of the gabbro is given in column I on page 95.

Diabase.

Several diabase dikes are exposed in the underground workings on the General Electric Company's property. The largest one (Spec. 146) is exposed in the surface cut 180 feet north of the shaft and was cut again on both the adit and 100-foot levels. It is 2 feet wide, has a uniform dip of 49° towards the south, and a strike of N. 63° E. It is a dark gray, fine-grained, massive rock in which small grains of pyrrhotite and ilmenite (?) may be distinguished by the naked eye. A thin section of the rock studied under the microscope shows it to be a very fine-grained uralitic basalt of granular rather than ophitic texture. The augite is altered to brown biotite and fibrous hornblende accompanied by the separation of minute particles of black iron oxide. Irregular grains and masses of magnetite or ilmenite partly altered to leucoxene are abundant.

A diabase dike cutting the gabbro in the east drive from the adit has been described on page 191. It was too badly altered to admit of microscopic study.

Several small dikes of diabase were encountered in the cross-cut on the 100-foot level 20 feet north of the shaft. They range in width from 12 inches down to less than an inch, observing a strike of about N. 20° E. A specimen (144) was collected, showing one of the dikes encased in the feldspathic syenite. The contact between the diabase and syenite is not a perfect plane but a series of small wave-like curves. Slight branches of the diabase approximately parallel to the main stringer penetrate into the syenite, and there are minor inclusions of the syenite in the diabase. The diabase is very fine-grained at the contact but grades into a slightly coarser rock at the centre of the dike. Lath-like feldspar crystals 1 mm. long can be distinguished which appear to be more plentiful near the contact. Under the microscope a thin section showed it to be an olivine diabase of microporphyritic texture composed chiefly of augite, large perfect laths of plagioclase feldspar (labradorite), olivine, magnetite, and rutile. Olivine is partly developed with idiomorphic form, shows its usual characteristics, and contains in a few instances inclosures of the other minerals. There is frequently associated with it granular aggregates and squarish crystals of greenish-brown rutile. Rutile is quite abundant. The other minerals show no unusual characters.

THE RUTILE ORE.

GENERAL STATEMENT.

Lithologically two distinct types of rutile occur in the Amherst-Nelson counties region and each has been mined. In the first type, designated syenite (formerly called pegmatite) rutile, the rutile occurs chiefly as disseminated grains of various sizes and as segregations in the form of wavy lines modified by dynamic metamorphism, in the coarse-grained syenite. In the second type, designated nelsonite rutile, the rutile occurs in the even-granular rock nelsonite, having dikelike characters and composed normally of apatite and ilmenite. These two occurrences of the rutile, including petrologic characters and chemical analyses, are described in the following pages.

SYENITE RUTILE.

Megascopic character.—The syenite rutile is red to reddish-brown in color, has a metallic-adamantine lustre, and is remarkably pure. The rutile grains vary in size from very minute granules, almost microscopic in dimensions, up to masses weighing many pounds. A single mass of pure rutile now in the Survey collections at the University of Virginia, found on the Bryant farm, 1.5 miles west of Rose Union, during the progress of field work on this report, weighs 49 pounds.

The rutile occurs as an original mineral irregularly distributed through the rock, ranging from sparsely disseminated grains to segregations which locally make up probably 30 per cent or more of the entire rock mass. The probable average where worked by the American Rutile Company near Roseland in the syenite is about 4 or 5 per cent. The mineral occurs as separate crystalline grains and aggregates with in no instance any indication megascopically of crystal boundaries observed. Although careful search was made in the field for rutile crystals not one was found.

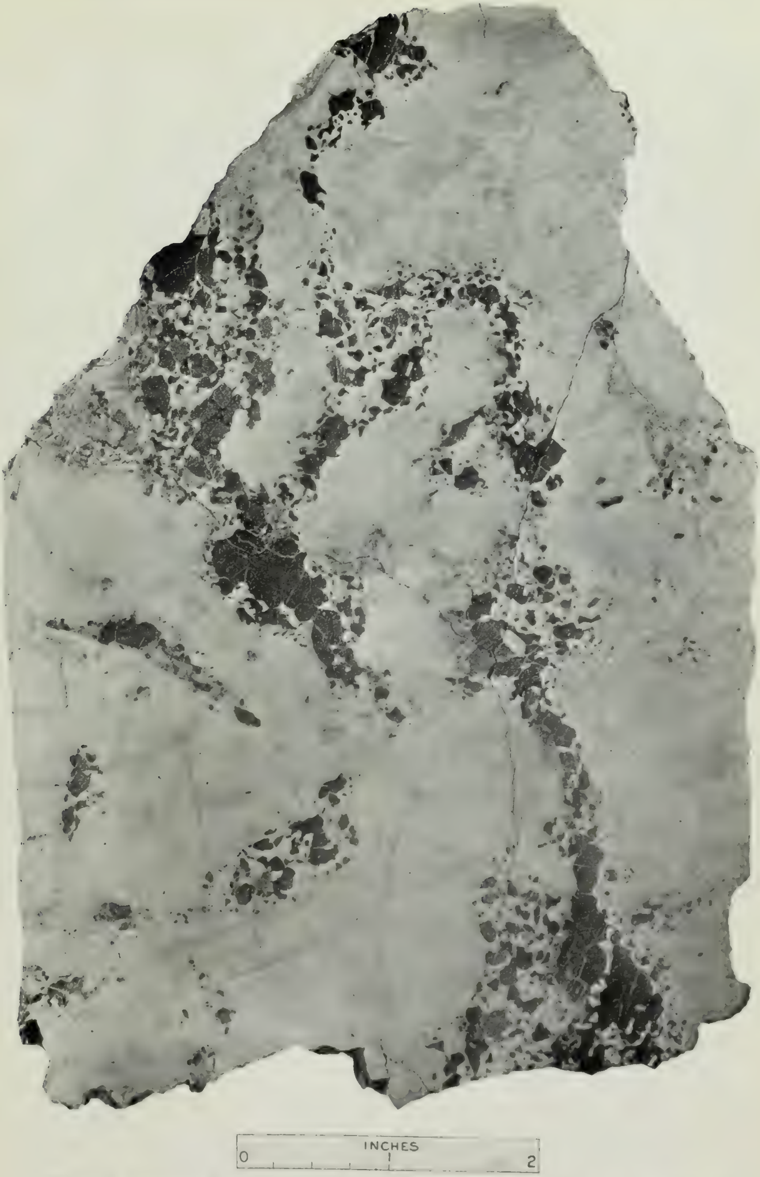
A possible explanation for the absence of rutile crystals may be the effect of intense though unequal dynamic metamorphism to which the rocks of the area have been subjected since their formation. Segregations of rutile in the syenite, showing mashing from dynamic forces, occur as irregular wavy lines or stringers composed of disconnected rutile grains of variable size (Pl. XXXIII). Segregations of this character are worked by the American Rutile Company near Roseland and occur in the same rock at other places in the district, especially about 700 yards southwest of the American Rutile Company's quarries, in the bluff bordering the lowlands on the west side of Tye River (p. 84, Pl. XXXIII), on the Hubard farm (p. 82), and on the Cox farm 1.5 miles northwest of Rose Union (page 81). Where hornblende has developed in quantity the rock has been crushed into a gneiss, elsewhere or in the more feldspathic facies of the rock gneissic structure is less emphasized.

The rutile occurs similarly in the syenite in each of the three rock-forming minerals—feldspar, quartz, and secondary hornblende (actinolite)—and locally is associated with some ilmenite, especially in the quartz and hornblende (uralite). It is disseminated at times quite uniformly in places through the feldspathic portions of the rock, and so far as mining operations have extended, the rutile associated with this facies of the rock is practically free from ilmenite and other iron-bearing minerals. When present ilmenite has a similar mode of occurrence to rutile with which it is intimately associated. The rock is remarkably free from other metallic minerals. Apatite is closely associated locally with the rutile, especially where large segregated masses of rutile are found in the syenite.

Composition of the rutile.—A sample of rutile from the "A" grade concentrates of the American Rutile Company, quarried and milled from the openings in syenite along Tye River, was further purified and analyzed with the following results:

Analysis of rutile from syenite near Roseland, Nelson County.
(WM. M. THORNTON, JR., *Analyst.*)

	Per cent.
TiO_2	95.71
FeO	2.35
SiO_2	0.92
Al_2O_3	n. d.
Cr_2O_3	0.02
V_2O_3	0.15
MnO	Trace
Total	99.15
Specific gravity	4.196



Polished specimen of rutile-bearing feldspathic facies of syenite from outcrop on American Rutile Company's property across Tye River from their mill. Main mass is feldspar (andesine intergrown with orthoclase (microcline)) with scattered grains and streaks of blue quartz. Dark mineral is rutile. Note the curving broken lines. The feldspar has been recrystallized. The rough light gray patches are apatite. (Collected by Frank L. Hess. Photographed by U. S. Geol. Survey.)

RUTILE-BEARING FELDSPATHIC FACIES OF SYENITE.

The melting point determined on a part of the same sample of rutile by the Bureau of Standards gave 1,690° C. Attention is called in the analysis to the presence of chromium and vanadium, and its striking similarity to that of the nelsonite rutile on page 197, with which this one should be compared. Vanadium and chromium are present in both rutiles and in about the same ratio, with vanadium largely in excess of chromium in each case. Careful chemical tests fail to indicate the presence of either tin, columbium, or tantalum in the rutile.

Vanadium and chromium being among the rarer elements, they have not been generally sought for in analyses of rutile, and yet in the rutiles of this and foreign countries on which chemical and spectroscopic examinations have been made for these elements, vanadium with only one or two exceptions and frequently though less often chromium, have been shown to be present in percentage amounts ranging from a trace to considerably less than a fraction of 1 per cent. In every case where these elements have been determined in rutiles vanadium is in excess of chromium. As already stated analyses made of the rutile and ilmenite from the Virginia district indicate the presence of both vanadium and chromium in every instance.

Microscopic character.—Under the microscope the physical properties of the rutile are plainly marked and show no unusual characters. The rutile is usually red to reddish-brown, sometimes yellowish-brown in color, and at times exhibits fairly noticeable pleochroism, but often so slight as not to be observed. Cleavage and twinning are frequently developed and the individual grains are often partly or wholly rimmed by the colorless to light gray alteration product leucoxene (titanite) as border zones of variable width but usually very narrow. Leucoxene has also formed along fracture lines which frequently penetrate and cross the rutile grains as the result of dynamic metamorphism. Definite inclusions of other minerals are very rare, and when developed as separate grains adjacent to those of ilmenite the boundaries of the rutile and ilmenite are sharply defined.

Microscopic study of a large number of thin sections shows the rutile developed in crystalline grains irregularly disseminated through the rock-forming silicate minerals, and also formed between individual feldspar grains or between feldspar and quartz grains, and penetrating both minerals. Both angular interlocking boundaries and somewhat rounded non-interlocking boundaries are developed between individual rutile grains and those of the inclosing rock minerals.

Rutile has not developed along fracture lines, cleavage or twinning planes of the rock minerals, but it has formed in relations to the silicate minerals much after the fashion of primary metallic oxides or ore minerals in igneous rocks. Frequently the fractures which penetrate the silicate minerals also cross the included rutile grains. These relations indicate magmatic crystallization of the rutile with the associated rock-forming silicate minerals. There is no evidence for regarding the rutile to be of secondary origin, although the masses and grains of the mineral have been more or less crushed and broken in places from dynamic metamorphism, forming at times wavy lines of rutile grains of variable size (Pl. XXXIII).

NELSONITE RUTILE.

Megascopic character.—Nelsonite rutile is limited in occurrence to the dikelike bodies composed essentially or entirely of the ore minerals, ilmenite and apatite, the normal phase of the rock. The rutile-bearing bodies show all gradations in the ratio of rutile and ilmenite, from a granular mixture composed of dominant rutile and apatite with little or no ilmenite to one composed of ilmenite and apatite with or without subordinate rutile. Gradations between these two extremes are observed in the same body. The rock with dominant rutile and apatite in a given position in the nelsonite body may gradually pass with increasing depth or laterally into a phase of the rock composed essentially of ilmenite and apatite. Accessory pyrite, including probably pyrrhotite, in part at least secondary, is a constant though variable constituent of the rock.

The norms calculated from the analyses on page 147 of a representative ilmenite-bearing rutile nelsonite and of a representative rutile-bearing ilmenite nelsonite presented in tabular form below, illustrate the variation in rutile percentage and show the percentages of the three principal minerals.

Percentages of rutile, ilmenite, and apatite in representative nelsonites.

Name of rock	Rutile	Ilmenite	Apatite
Ilmenite-bearing rutile-apatite nelsonite	64.56	9.73	22.18
Rutile-bearing ilmenite-apatite nelsonite	5.76	60.65	29.57

A detailed description of the rutile nelsonite bodies is given on pages 117-123.

The nelsonite rutile is uniformly darker in color, both in hand specimens and in thin sections, than the rutile of the syenite. The reason for this difference of color is not entirely apparent since analyses of the two types of the mineral are closely similar, and it can not be ascribed to inequality of total iron content, but may be due to a difference of vanadium present. The rutile occurs in formless grains, not exceeding as a rule 3 mm. in size, although occasional segregations of coarse rutile which grade into nelsonite are observed (Pl. XV). Segregations of the rutile in the nelsonite bodies are less frequently developed than those of apatite. Detailed descriptions of the rutile nelsonite bodies are given on pages 117-123 to which the reader is referred.

Composition of the rutile.—An analysis of rutile isolated from specimens of rutile nelsonite at the General Electric Company's mine. 1.5 miles northwest of Rose's Mill, gave the following results.

Analysis of nelsonite rutile from near Rose's Mill, Nelson County.
(WM. M. THORNTON, JR., *Analyst.*)

	Per cent.
TiO_2	98.80
FeO	1.68
SiO_2	0.26
Cr_2O_3	0.07
V_2O_3	0.20
Total	101.01
Specific gravity	4.21

The melting point of the rutile from the same sample was determined by the Bureau of Standards to be 1,700° C. Comparison of this analysis with that of the syenite rutile on page 194 indicates their close similarity. The ratio of Cr_2O_3 and V_2O_3 in the two analyses is of the same general order.

Microscopic character.—In thin sections under the microscope the rutile presents no unusual characters. It is dark yellowish- to reddish-brown and sometimes though not always exhibits noticeable pleochroism, $E > O$. Both cleavage and twinning are frequently developed and the mineral is remarkably free from inclusions. Slight alteration to leucoxene peripherally and along irregular fractures is noted. The rutile is developed in formless crystalline grains, sometimes inclosing apatite, less often ilmenite when present, and in turn is inclosed by the same minerals. In most cases the evidence suggests nearly simultaneous crystallization with the other principal minerals. No evidence has been developed either from the field or laboratory study for regarding the rutile of the nelsonite bodies or that of the syenite as of secondary or subsequent origin.

Rutile-bearing nelsonite bodies have been exploited at several localities in the district, chiefly in the vicinity of Rose's Mill and Roseland.

LOVINGSTON DISTRICT.

INTRODUCTORY STATEMENT.

The country rock of the Lovingston district is a biotite-quartz monzonite-gneiss of the same general character as that described on pages 59-66. It is traversed by numerous dikes of coarse- (pegmatite) and fine-grained granite, and nelsonite. Some of the more important acid dikes are described below. Three varieties of nelsonite in which magnetite, biotite, and hornblende are, respectively, the dominant constituents occur in this district and are described under nelsonite on pages 123-138. Normal ilmenite and rutile nelsonite bodies are not found in the Lovingston district.

Biotite Gneiss.

Biotite gneiss of quartz monzonitic composition forms the principal rock type in the Lovingston district. It is identical with the outside gneiss of the Roseland district of which it is a part, and while minor variations in structure and composition are shown, its general character is everywhere the same. It varies from medium- to coarse-grained in texture, usually of medium gray color, and having a pronounced banded or schistose structure. Usually porphyritic texture is developed in the rock, the feldspar phenocrysts ranging up to 3 cm. in diameter. The direction of strike of the structure (schistosity) varies from N. 35° E. as measured in the large exposures of the rock 1.5 miles southwest of Lovingston to N. 57° E., three-quarters of a mile north of the town.

Along the slope of the ridge lying east of Lovingston are many exposures of the foliated biotite gneiss, partly as broad, smooth surfaces almost bare of vegetation which sometimes cover an area of half an acre in extent, and partly as sheet-like masses that project boldly from the side of the mountain in a direction parallel to the schistosity. The direction of strike of the schistosity is remarkably uniform throughout the section around Lovingston, rarely varying more than a few degrees from N. 40° E.

Feldspar, quartz, and biotite, in the order named, are the principal components of the rock readily distinguishable by the naked eye. Microscopically thin sections of the rock naturally exhibit some variation in mineral composition, a difference more one of proportion than of kind of minerals, described in detail on pages 61-63. In thin sections the minerals are feldspar (orthoclase and variant microcline, and plagioclase (oligoclase)), quartz, biotite, and occasionally hornblende. Colorless mica, kaolin,

General view of Lovingston and valley taken from ridge northwest of the town.

LOVINGSTON AND VALLEY.

epidote, chlorite, leucoxene, and sometimes a little zoisite are the secondary minerals derived chiefly from the alteration of the primary minerals feldspar and biotite. Accessory magnetite, zircon, apatite, and rutile as inclusions occur. Granulation and wavy extinction are pronounced in the quartz and to a less extent the feldspar. (See Pl. VI, fig. 3.) A chemical analysis of a representative specimen of the rock collected along the county road, three-quarters of a mile north of Lovingston, is given in column II on page 63.

Amphibolite.

Dikelike bodies of hornblendic rocks (amphibolite) occur in the Lovingston district but only two exposures were found that were fresh enough to indicate the true character of the rock. One of these is exposed in the county road about a mile northwest of Lovingston where a dike approximately 6 feet wide cuts the biotite-quartz monzonite-gneiss. The rock (Spec. 185) is fine-grained in texture and composed principally of hornblende with some feldspar and a little magnetite or ilmenite. A few scattered phenocrysts of feldspar about 0.5 cm. in diameter are present. A thin section of the rock shows the principal mineral to be blue-green and brown hornblende in irregular fibrous to columnar masses partly intergrown with shreds of brown biotite. A little plagioclase feldspar and magnetite or ilmenite partly altered to leucoxene also occur. Most if not all the hornblende is secondary derived possibly from pyroxene.

About a mile southwest of Lovingston a second dike of a similar rock, about 50 yards wide and having a northeast-southwest direction of strike, is crossed by the county road. Most of the rock exposed is greatly altered from weathering, but several fairly fresh pieces were obtained which indicate a fine- to medium-grained texture. The minerals visible in the hand specimens are chiefly hornblende, some feldspar and ilmenite or magnetite, and occasional graphite in tiny flakes. A microscopic study of thin sections of the rock (Specs. 172 and 173) shows similar composition to the rock described above (Spec. 185). Fibrous blue-green and platy brown hornblende is the principal mineral. Some unstriated feldspar probably andesine, shreds of brown biotite, and occasional apatite occur. Epidote, zoisite, leucoxene, and iron oxide occur as secondary minerals.

A similar rock is observed outcropping on the side of the ridge half a mile east of Lovingston. The secondary character of most if not all of the hornblende in these rocks is clearly indicative of their derivation from another rock type of probable gabbroic composition, although no trace of pyroxene was distinguishable in the thin sections.

Pegmatite and Granite Dikes.

In the vicinity of Lovingston, the biotite-quartz monzonite-gneiss is cut by numerous pegmatite and granite dikes of similar but more acid composition than the inclosing gneiss, ranging from fine- to coarse-grained in texture, and from a few inches up to 10 or 12 feet in width. The dikes seldom occur singly but usually in groups of two or three that are parallel in strike to the structure of the gneiss. The granite is more resistant to weathering than the gneiss and therefore the dikes usually stand out in relief, sometimes for as much as two inches. Sketch, fig. 17, shows the appearance of some of the dikes exposed on the mountain slope about three-quarters of a mile northeast of Lovingston.

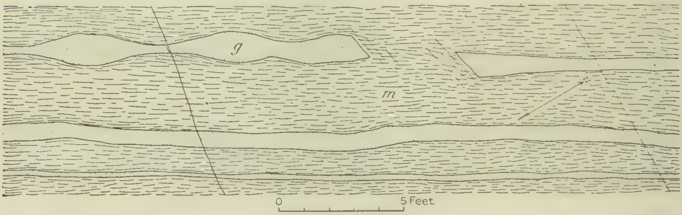


Fig. 17.—Sketch of granite dikes in biotite-quartz monzonite-gneiss on mountain slope 0.75 mile north of Lovingston, Nelson County. (*g*) Granite dikes, (*m*) biotite-quartz monzonite-gneiss.

Pegmatite dikes.—The following description of a single pegmatite occurrence may be taken as representative of this class of materials in the district: A pegmatite dike about 6 feet wide is exposed on the south side of the county road 1.5 miles southwest of Lovingston. The rock is coarse-grained in texture composed for the most part of feldspar and quartz with only a very small amount of biotite. The quartz is partly dark blue to gray in color and partly white to transparent. A thin section of the rock (Spec. 161) shows the principal minerals to be feldspar (orthoclase partly perthitic, some microcline but no separate individuals of striated plagioclase) and quartz. Both the feldspar and quartz contain inclusions of both euhedral and anhedral forms. The inclusions in the quartz include rutile needles and apatite, some of the former being curved, bent, and broken. The usual microscopic evidence of dynamo-metamorphism is manifested in the thin section.

Granite dikes.—The rock of these dikes is light gray in color, medium- to fine-grained in texture, and composed chiefly of feldspar and quartz with but little mica. The quartz exhibits a variety of color ranging from bluish to gray and dark smoky. The dikes range up to 12 feet in width and in some cases are intruded into the gneiss parallel to the structure (schistosity). Thin sections (Specs. 179, 181, 183, and 194) show the principal minerals to be orthoclase partly perthitic, some microcline, and variant plagioclase, which in some sections may equal in amount the potash feldspars, quartz, and biotite. Minor accessory minerals include rutile needles as inclusions in the quartz, apatite, and magnetite or ilmenite. The secondary minerals are colorless mica (muscovite), epidote, zoisite, kaolin, chlorite, and iron oxide stain. Dynamic metamorphism is usually manifested in granulation and wavy extinction of the quartz and to a less extent in bent and broken plagioclase lamellæ.

Nelsonite.

Magnetite, biotite, and hornblende nelsonites occur in the Lovingston district but no dikes of normal ilmenite or rutile nelsonite have been found. The magnetite and biotite nelsonites are found on the north, west, and southwest sides of Lovingston, respectively, within a radius of 2 miles. These are described in detail, including a chemical analysis of the occurrence on the Dillard farm 2 miles southwest of Lovingston, on pages 123-133. Hornblende nelsonites have been noted on the north, west, and southwest sides of Lovingston, respectively, and are described including a chemical analysis on pages 133-138.

GENERAL PETROLOGY OF THE AMHERST-NELSON COUNTIES REGION.

INTRODUCTION.

The igneous rock types forming the complex in Amherst and Nelson counties show certain features known as clan characters, which group them into a definite family distinguished from rock groups elsewhere. The area is a distinct comagmatic region or petrographic province. In the Virginia region the clan characters are in part mineralogical and in part chemical. Texture is a less important feature.

Mineralogically the rocks are characterized by the prominence of apatite and the titanium minerals—ilmenite, rutile, and in a few places titaniferous magnetite; by a peculiar blue opalescent quartz; by pyroxene (chiefly hypersthene) or secondary amphibole (actinolite) derived from the pyroxene as the dominant mafic (ferromagnesian) mineral, and microscopically by the chief feldspar being plagioclase, having the composition of andesine containing spindle-shaped intergrowths of microcline. Biotite, an important constituent in the surrounding quartz monzonite-gneiss is only sparingly developed in the ore-bearing rocks. It is only of importance in biotite nelsonite which occurs in the quartz monzonite-gneiss. In general the dominant minerals in one type make up the minor accessory minerals in the other. Graphite, while not uniformly distributed in the rocks of the area, occurs in practically all rock types and in places is an important constituent.

These mineral peculiarities are of course dependent on the chemical composition of the magmas and the physical conditions under which they solidified.

GEOLOGIC OCCURRENCE.

The geologic occurrence of the rocks has been described separately under each type in a previous chapter. It is only necessary here to briefly summarize their occurrence for the region as a whole.

The rocks of the region are all intrusive and holocrystalline in texture. Most of them are even-granular, ranging from very coarse-grained in the syenite to very fine-grained in some of the nelsonite and diabase dikes. Porphyritic texture is observed in some of the nelsonite and gabbro-nelsonite dikes. The bulk of the rocks, including quartz monzonite-gneiss, syenite (feldspathic and hornblendic border facies), and a part of the gabbros and nelsonites are deep-seated (plutonic) masses, traversed by dikes of gabbro, diabase, and nelsonite. These are genetically related, and with the exception of diabase nearly all gradations in composition are indicated between the extremes of the different types.

The dikes are most abundant within the rutile-bearing syenite, but they are by no means confined to it and in places are observed beyond the limits of this formation in the outside gneiss. They vary greatly in width, and in many places show almost as great variation in strike, although most of them conform to a general northeast-southwest direction.

The indications from field study are that the syenite and deep-seated gabbro usually grade into each other, sharp contacts being but seldom observed. Likewise between the gabbro and nelsonite occur nearly all gradations in mineral composition, from typical hypersthene gabbro (norite) containing subordinate apatite and ilmenite to typical nelsonite containing little or none of the silicate minerals.

The rocks exhibit pronounced though unequal effects of dynamic metamorphism, both in hand specimens and in thin sections under the microscope. The most pronounced effect of metamorphism visible in hand specimens of most of the rocks is the development of complete or partial banded or gneissic structure. Microscopically metamorphism is manifested chiefly in mashing—granulation, fractures, and optical disturbance of certain essential minerals—in recrystallization, and in the complete or partial change of pyroxene (hypersthene) to secondary hornblende (actinolite).

Other changes of a different order and kind involve the production of secondary minerals from the essential ones, chief among which are the formation of leucoxene from the titanium minerals rutile and ilmenite, and sericite, epidote, and zoisite from feldspar. In some of the rocks biotite, chlorite, and osteolite are noted as alteration products.

CHEMICAL CHARACTERS.

For the purpose of study of the chemical characters of the Amherst-Nelson counties region, 28 analyses which have been presented in the preceding pages are assembled in the annexed tables. They are complete and accurate analyses made by the State Survey chemist according to the latest approved methods of the U. S. Geological Survey. They include every type occurring in the region, and each type is represented by several analyses made on representative specimens collected from occurrences at different localities in the region.

The analyses of the silicate rocks are arranged in the order of decreasing silica; those of the ore rocks (nelsonites) are arranged in the order of decreasing titania.

Table of analyses of silicate rocks from Nelson County, Virginia.

(Wm. M. Thornton, Jr., *Analyst.*)

	I	II	III	IV	V	VI	VII	VIII
SiO_2	66.46	63.61	63.40	61.51	60.03	59.92	59.84	57.74
Al_2O_3	14.94	15.70	15.94	23.17	21.38	24.23	20.59	18.90
Fe_2O_3	1.87	1.98	2.01	0.37	0.50	0.29	0.55	1.42
FeO	3.08	3.81	3.91	0.26	0.25	0.24	0.71	3.87
MgO	1.11	3.58	1.33	0.26	0.19	0.23	0.76	3.52
CaO	3.10	4.50	3.75	5.96	4.59	6.47	4.48	6.42
Na_2O	2.63	3.47	3.53	4.64	5.80	5.03	5.23	3.74
K_2O	4.74	2.12	3.30	3.94	2.81	2.93	2.57	1.72
H_2O-	0.06	0.14	0.06	0.08	0.16	0.08	0.18	0.06
H_2O+	0.80	0.97	0.76	0.03	0.66	0.28	0.75	1.11
TiO_2	0.83	0.40	1.33	0.29	3.66	0.22	3.75	1.24
P_2O_5	0.29	0.15	0.55	0.10	0.39	0.09	0.35	0.28
MnO	0.05	0.05	0.07	Trace	0.01	Trace	0.02	0.02
CO_2	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace
S	Trace	Trace	Trace	Trace	None	Trace	None	0.20
Total	99.96	100.48	99.94	100.90	100.43	100.01	99.78	100.19

Table of analyses of silicate rocks from Nelson County, Virginia (Continued).

	IX	X	XI	XII	XIII	XIV
SiO_2	56.61	54.80	52.83	52.34	51.08	50.99
Al_2O_3	14.89	14.28	13.79	12.46	16.45	12.40
Fe_2O_3	1.04	3.08	4.42	3.37	0.84	2.10
FeO	4.32	7.55	7.86	10.08	10.08	11.80
MgO	4.05	2.52	5.61	3.97	6.95	4.09
CaO	4.94	6.57	8.99	7.88	5.57	6.46
Na_2O	3.19	2.61	2.42	2.26	3.49	2.38
K_2O	1.51	2.00	1.46	1.66	1.28	2.19
H_2O-	0.08	0.16	0.71	0.14	0.08	0.12
H_2O+	1.58	1.23	1.30	1.46	0.51	1.21
TiO_2	7.26	4.15	1.18	2.96	4.44	4.66
P_2O_5	0.26	0.70	0.31	1.19	0.14	1.86
MnO	0.01	0.02	n. d.	0.11	0.08	0.11
CO_2	0.22	Trace	Trace	Trace	Trace	Trace
S	0.03	0.02	Trace	0.18	Trace	Trace
Total	99.99	99.69	100.88	100.06	100.99	100.37

Table of analyses of silicate rocks from Nelson County, Virginia (Continued).

	XV	XVI	XVII	XVIII	XIX	XX
SiO_2	50.97	49.65	48.99	33.89	33.83	20.02
Al_2O_3	13.13	13.93	13.93	0.94	5.19	2.64
Fe_2O_3	1.44	4.11	2.45	6.85	11.38	11.75
FeO	5.42	9.78	10.94	22.73	15.08	16.98
MgO	4.68	4.89	6.29	6.85	8.57	5.93
CaO	3.66	9.05	10.02	9.68	8.22	10.27
Na_2O	2.72	2.86	2.59	0.37	1.28	0.23
K_2O	2.24	1.71	0.80	0.34	0.50	0.39
H_2O-	0.05	0.09	0.09	0.32	0.45	0.71
H_2O+	1.41	1.49	1.47	1.66	0.75	2.47
TiO_2	13.64	3.03	3.33	12.97	10.00	20.73
P_2O_5	0.31	0.32	0.33	3.29	4.84	7.34
MnO	0.05	0.14	0.11	0.31	0.26	0.23
CO_2	0.04	Trace	Trace	Trace	Trace	Trace
S	None	0.20	Trace	None	0.26	None
Cl	.....	.....	.....	0.01	0.04	0.02
F	.....	.....	.....	0.02	0.55	0.31
Total	99.76	101.20	101.34	100.23	101.09	99.89

I. Quartz-biotite monzonite-gneiss, county road, 0.75 mile north of Lovingston.
II. Hornblendic facies of syenite, 100-foot level, General Electric Co.'s mine, 1.5 miles northwest of Rose's Mill.
III. Quartz-biotite monzonite-gneiss, Arrington-Roseland road, 1 mile north of Colleen.
IV. Feldspathic (gray) facies of syenite, 100-foot level, General Electric Co.'s mine, 1.5 miles northwest of Rose's Mill.
V. Feldspathic facies of syenite, American Rutile Co.'s quarries, Roseland.
VI. Feldspathic (pinkish) facies of syenite, 100-foot level, General Electric Co.'s mine, 1.5 miles northwest of Rose's Mill.
VII. Average bulk sample of syenite, including hornblende and feldspar facies, American Rutile Co.'s quarries, Roseland.
VIII. Gabbro-gneiss along east side of Tye River, 430 feet south of American Rutile Co.'s south quarry.
IX. Hornblendic facies of syenite, American Rutile Co.'s quarries, Roseland.
X. Gabbro-gneiss along east side of Tye River, 525 feet south of American Rutile Co.'s south quarry.
XI. Diabase dike, east side of county road, 100 yards north of Piney River at Rose's Mill.
XII. Diabase (basalt) dike, east side of Tye River, 425 feet south of American Rutile Co.'s south quarry.
XIII. Gabbro dike, Roseland-Arrington road, near Mr. Adams' house, 100 yards south of Roseland post-office.
XIV. Gabbro dike, 100-foot level, 50 feet from shaft, General Electric Co.'s mine, 1.5 miles northwest of Rose's Mill.
XV. Hornblendic facies of syenite, American Rutile Co.'s quarries, Roseland.
XVI. Diabase (basalt) dike, Roseland-Arrington road, near Mr. Adams' house, 100 yards south of Roseland post-office.
XVII. Diabase (basalt) dike, south side of Piney River, opposite General Electric Co.'s mine, 1.5 miles northwest of Rose's Mill.
XVIII. Hornblende nelsonite, 3 miles north of Lovingston.
XIX. Gabbro-nelsonite dike, west of Roseland-Arrington road, 1 mile south of Roseland post-office.
XX. Hornblende (biotite-chlorite) nelsonite, 1 mile west of Rose's Mill.

Table of analyses of nelsonite from Nelson County, Virginia.
(WM. M. THORNTON, JR., *Analyst.*)

	I	II	III	IV	V	VI	VII	VIII
TiO_2	69.67	65.90	42.84	41.46	37.68	37.00	16.48	15.78
Fe_2O_3	2.87	3.65	11.12	15.59	2.70	4.31	43.34	37.45
FeO	5.04	7.95	27.93	23.57	29.14	26.52	18.61	20.20
MgO	0.15	0.25	0.72	0.50	0.50	1.11	0.66	0.64
CaO	12.16	11.13	8.34	9.03	16.05	16.33	5.48	12.73
P_2O_5	9.41	8.14	6.89	7.59	12.48	13.08	4.98	9.40
H_2O-	0.09	0.21	0.15	0.53	0.03	0.09	0.51	0.20
H_2O+	0.11	0.35	0.58	0.87	.....	0.59	1.62	0.97
F	0.70	0.34	0.21	0.17	1.03	0.98	0.26	0.23
Cl	Trace	None	0.01	Trace	Trace	Trace	Trace	Trace
SiO_2	0.67	0.95	0.70	1.65	.....	0.57	4.24	1.24
MnO	.....	0.26	0.18	0.26	Trace	0.38	0.12	0.23
Al_2O_3	.....	.....	.....	.....	.....	.....	3.45	n. d.
Na_2O	.....	.....	.....	.....	.....	.....	0.15	0.10
K_2O	.....	.....	.....	.....	.....	.....	0.45	0.34
CO_2	.....	Trace	Trace	Trace	Trace	Trace	Trace	.....
S	0.34	1.61	.....	.....	1.17	1.45	Trace	.....
Total	100.82	100.19	99.58	101.15	100.06	101.62	100.24	99.42

I. Rutile nelsonite from ore-dump, General Electric Co.'s mine, 1.5 miles northwest of Rose's Mill.
II. Rutile nelsonite dike, Giles tract near Roseland.
III. Ilmenite nelsonite dike, Shelton farm, 1 mile northwest of Roseland.
IV. Ilmenite nelsonite dike, Hight place, 1.75 miles west of north from Roseland.
V. Ilmenite nelsonite from ore-dump, General Electric Co.'s mine, 1.5 miles northwest of Rose's Mill. Specimen probably taken from No. 1 ore-body in the adit level.
VI. Ilmenite nelsonite from ore-dump, General Electric Co.'s mine, 1.5 miles northwest of Rose's Mill.
VII. Magnetite-biotite nelsonite dike, Stevens farm, 0.5 mile west of Lovingston.
VIII. Magnetite-biotite nelsonite dike, Dillard farm, 2 miles southwest of Lovingston.

The important features to be noted in these analyses can best be discussed by averaging and tabulating under a single analysis the several analyses of each type, of all types represented as given in the annexed table below. The nelsonites, represented by 8 analyses, are given in a separate table, and their chemical composition, comparing graphically the molecular proportions of the rocks by means of a diagram, is fully discussed on pages 145-148.

A study of the individual analyses of the above tables reveals, as would be expected, some variation in the constituents of the same type, but when considered broadly the analyses show that with decreasing silica and alumina there is increase of iron, lime, magnesia, titania, and phosphoric acid.

Table of averages of analyses of silicate rocks from Nelson County, Virginia.
(WM. M. THORNTON, JR., *Analyst.*)

	I	II	III	IV	V	VI	VII
SiO_2	64.93	60.44	57.06	53.65	51.23	33.83	26.96
	1.082	1.007	.951	.894	.854	.564	.449
Al_2O_3	15.44	23.62	14.54	15.51	13.53	5.19	1.79
	.151	.231	.142	.152	.132	.051	.018
Fe_2O_3	1.94	0.29	1.49	1.86	3.59	11.38	9.30
	.012	.002	.009	.012	.023	.071	.058
FeO	3.50	0.19	4.52	8.33	9.67	15.08	19.86
	.049	.003	.063	.115	.133	.251	.276
MgO	1.22	0.21	4.10	4.27	5.19	8.57	6.39
	.030	.005	.102	.106	.129	.214	.159
CaO	3.43	5.59	4.37	6.26	8.99	8.22	9.98
	.061	.100	.079	.113	.161	.146	.179
Na_2O	3.08	4.49	3.13	3.06	2.53	1.28	0.30
	.050	.073	.050	.050	.040	.021	.005
K_2O	4.02	3.37	1.96	1.80	1.41	0.50	0.37
	.043	.036	.021	.019	.015	.005	.004
H_2O-	0.06	0.08	0.09	0.11	0.26	0.45	0.52
	.006	.006	.006	.006	.017	.028	.028
H_2O+	0.78	0.32	1.32	1.02	1.43	0.75	2.07
	.044	.017	.072	.056	.078	.044	.117
TiO_2	1.08	1.11	7.10	3.62	2.63	10.00	16.85
	.014	.014	.089	.045	.033	.124	.210
P_2O_5	0.42	0.15	0.24	0.75	0.54	4.84	5.32
	.003	.001	.001	.006	.004	.034	.037
MnO	0.06	Trace	0.04	0.06	0.09	0.26	0.27
	.001			.001	.001	.004	.004
CO_2	Trace	Trace	0.09	Trace	Trace	Trace	Trace
S	Trace	Trace	Trace	Trace	Trace	0.26	.....
Cl	.....	.....	.....	.....	.....	0.04	0.02
F	.....	.....	.....	.....	.....	0.55	0.17
						.032	.011
Total	99.96	100.31	100.05	100.30	100.09	101.09	100.17

I. Average of two analyses of quartz monzonite-gneiss.
II. Average of four analyses of feldspathic facies of syenite.
III. Average of three analyses of hornblendic border facies of syenite.
IV. Average of four analyses of gabbro.
V. Average of four analyses of diabase.
VI. One analysis of gabbro-nelsonite.
VII. Average of two analyses of hornblende nelsonite.

In the annexed table are assembled the averages of analyses of all types of silicate rocks found in the district, a total of seven types. VI and VII, containing very low silica, are regarded as transitional types between the silicate rocks and ore rocks (nelsonites), since they are composed of both silicate and ore minerals in large amounts but in unequal proportions. A study of the analyses shows that the rocks are low in silica, which ranges from 65 to 27 per cent—65 to 51 per cent in the silicate rocks proper (I to V inclusive) with an average of about 57 per cent. Alumina is extremely low in VI and VII, but for the silicate rocks proper (I to V) it is quite uniform except in II, where it is appreciably higher as the rock is composed chiefly of feldspar—the feldspathic facies of the syenite.

The iron, magnesia, and lime increase with diminishing silica and alumina. Except in II, FeO is in considerable excess over Fe_2O_3 and both increase with diminishing silica but not in the same ratio. The ratios of the alkalies (soda and potash) are variable, but in each type soda molecularly exceeds potash. This predominance of soda together with high lime marks the dominant feldspar in the rocks as a soda-lime plagioclase.

Attention is especially directed in the table of analyses to the percentages of TiO_2 and P_2O_5 which are above the average for the types of rocks represented, and in some types their combinations make up the important minerals that enter into the composition of the rocks. They increase though unequally from the more acid to the more basic types, reaching a maximum in the extreme basic ones (nelsonites, analyses and their discussion, pages 145-148) in which their combinations as apatite, rutile, and ilmenite form the essential minerals. These two constituents (TiO_2 and P_2O_5) form one of the distinctive features of the rock types of the region, and they emphasize the kinship of the types, which must have sprung from a common parent magma.

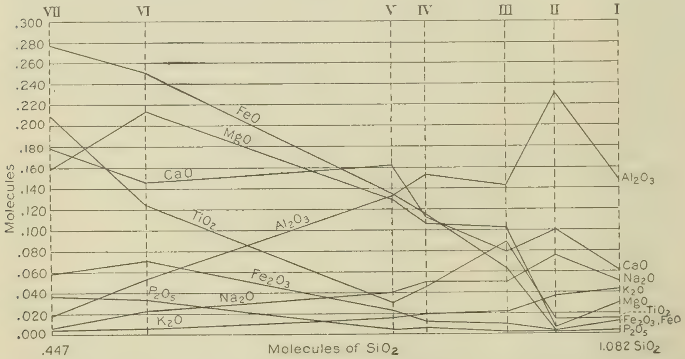


Fig. 18.—Diagram showing variation in the molecular constituents of the seven types of silicate rocks in the Amherst-Nelson counties area. Based on table of averages of analyses. (Order of diagram reversed from that in the table of analyses, page 207.)

The above relationships developed from chemical composition of the rocks are best shown in the diagram, fig. 18, which compares graphically the molecular proportions of the oxides and is constructed from the analyses in table on page 207, by plotting the molecular proportions of the oxides as ordinates, and those of silica as abscissas. Study of the diagram, fig. 18, discloses certain irregularities in the molecular proportions of the oxides, which correspond to variations in the proportions of the essential minerals.

The ferrous and ferric oxides show somewhat general correspondence with each other, being represented by the same line in I and II, the extreme acid end of the series. They increase from the acid to the basic end of the series, which corresponds to variations in the proportions of salic and femic minerals, the principal iron-bearing femic minerals being pyroxene and its alteration product hornblende, and ilmenite. With increase of ilmenite, which is greatest in VI and VII, the lines representing the iron oxides become wider spaced with slight irregularities indicated, and ferrous oxide becomes the dominant constituent, attaining its maximum value in VII, the lowest silica-bearing rock of the series.

On the whole magnesia varies in the same direction with the iron oxides, but is erratic at times with respect to ferrous oxide. The correspondence might possibly be closer were all the iron reduced to the ferrous state, but this has not been attempted.

Discordance between magnesia and alumina is strongly marked and except for the basic end of the series they vary in opposite directions. Lime and alumina vary in the same direction on the acid end of the series, but are antagonistic on the basic end in which rocks feldspar almost entirely fails and apatite becomes an important constituent. The alkalies, soda and potash, vary in general with the alumina with which there is a fairly close correspondence. They increase from the basic to the acid end of the series, but there is a more marked accordance between soda and alumina than between potash and alumina. The soda molecules are greater than those of potash, being more than twice as large in some cases.

Titania and phosphoric acid, especially the former, are erratic for the acid end of the series and increase in amount, though unequally toward the basic end, both attaining their maximum in VII, in which rock ilmenite and apatite are important constituents.

The irregularities to which attention has been directed are due to variations in the molecular proportions of the essential minerals present in the rocks. At the acid end of the series the salic minerals (feldspars chiefly with some quartz) predominate; in the middle of the series, IV and V, femic minerals become more prominent; and at the basic end salic minerals practically fail and the rocks are composed almost entirely of femic minerals, both ore minerals and ferromagnesian silicates being the essential ones.

NORMS OF AMHERST-NELSON COUNTIES ROCKS.

In the subjoined tables are given the norms of the different rocks calculated from the analyses in the preceding tables, and arranged in the same order. Their study will make clearer the chemical relations of the rocks, especially their relations to the quantitative system. Some of them represent new rock types, described and published for the first time. The positions of the new types in the quantitative system have been calculated and appropriate names have been suggested for them in the preceding pages.

Norms of silicate rocks of Amherst-Nelson counties.

	I	II	III	IV	V	VI	VII	VIII
Quartz	24.42	18.80	20.00	6.66	5.70	5.82	9.48	9.72
Orthoclase	27.80	12.23	19.46	23.35	16.68	17.24	15.57	10.01
Albite	22.01	29.34	29.87	39.30	49.25	42.44	44.02	31.44
Anorthite	13.62	21.13	15.29	28.63	21.68	31.14	20.57	29.79
Corundum	0.51	.....	0.92	0.71	0.82	1.33	1.63	.....
Diopside	.....	.....	.....	.....	.....	.....	.....	0.46
Hypersthene	5.84	13.52	6.60	0.60	0.50	0.60	1.90	12.30
Magnetite	2.55	3.02	3.02	.....	.....	.....	.....	2.09
Ilmenite	1.52	0.76	2.58	0.61	0.61	0.46	1.52	2.43
Hematite	.....	.....	.....	0.48	0.48	0.32	0.48	.....
Rutile	.....	.....	.....	.....	3.36	.....	2.96	.....
Apatite	0.62	0.34	1.24	0.14	1.01	0.34	0.67	0.62
Pyrite	.....	.....	.....	.....	.....	.....	.....	0.36
H_2O	0.86	1.11	0.82	0.40	0.82	0.36	0.93	1.17
	99.75	100.25	99.80	100.88	100.91	100.05	99.73	100.34
Rest	.....	.05	.....	.....	.....	.....	0.02	.....
Total	99.75	100.30	99.80	100.88	100.91	100.05	99.75	100.34

	IX	X	XI	XII	XIII	XIV	XV	XVI
Quartz	16.26	15.54	6.96	11.10	.....	8.94	12.36	1.26
Orthoclase	8.90	11.68	8.34	10.01	7.23	12.79	12.79	10.01
Albite	27.25	22.01	19.91	18.86	29.34	19.91	23.06	24.10
Anorthite	21.68	21.41	22.80	18.90	25.58	16.68	16.96	20.29
Diopside	.....	5.78	16.32	11.14	0.92	3.43	.....	19.24
Hypersthene	10.10	7.90	15.27	14.89	27.53	21.05	11.70	11.96
Magnetite	.....	4.41	6.26	4.87	1.16	3.02	.....	6.03
Ilmenite	9.11	7.90	2.28	5.62	8.36	8.82	11.40	5.78
Hematite	0.96	.....	.....	.....	.....	.....	1.44	.....
Titanite	1.37	.....	.....	.....	.....	.....	0.39	.....
Rutile	1.94	.....	.....	.....	.....	.....	7.44	.....
Apatite	0.67	1.15	0.62	2.48	0.31	4.03	0.67	0.62
Pyrite	.....	.....	.....	0.36	.....	.....	.....	0.36
H_2O	1.66	1.39	2.01	1.60	0.59	1.33	1.46	1.58
	99.90	99.61	100.77	99.83	101.02	100.00	99.67	101.23
Rest	.26	.....	.....	.....	.....	.....	0.09	.....
Total	100.16	99.61	100.77	99.83	101.02	100.00	99.76	101.23

	XVII	XVIII	XIX	XX
Quartz	0.42	7.86	7.86	7.50
Orthoclase	5.00	1.67	2.78	2.22
Albite	22.01	3.14	11.00	1.57
Anorthite	23.91	.....	6.95	.....
Corundum	.....	.....	.....	1.84
Diopside	20.42	21.92	.....	.....
Hypersthene	17.30	20.97	23.12	14.80
Magnetite	3.48	9.98	16.47	.....
Ilmenite	6.38	24.78	19.00	36.33
Hematite	.....	.....	.....	11.68
Titanite	.....	.....	.....	3.53
Rutile	.....	.....	.....	0.16
Apatite	0.68	7.73	11.42	16.80
Pyrite	.....	.....	0.48	.....
H_2O	1.56	1.98	1.20	3.18
Total	101.10	100.03	100.59	99.61

Summary of Classification.

No.	Symbol	Name
I.	I′. 4. 2′. 3.	Toscanose
II.	′II. 4. 3. 4.	Tonalose
III.	′II. 4. 2′. 3′.	Adamellose
IV.	I. 5. 3. 4.	Piedmontose
V.	I. 5. ′3. 4.	Piedmontose
VI.	I. ′5. 3. 4.	Piedmontose
VII.	I′. ′5. 2. 4.	Laurvikose
VIII.	′II. ′5. 3′. 4.	Hessose-andose
IX.	II. 4. 3. 4.	Tonalose
X.	II. 4. 3. ′4.	Tonalose
XI.	′III. ′5. 3′. 4.	Camptonose
XII.	′III. 4. 3. ′4.	Vaalose
XIII.	′III. 5. 3′. 4.	Andose-camptanose
XIV.	′III. 4′. 3. ′4.	Vaalose
XV.	II′. 4. 3. ′4.	Tonalose
XVI.	III. 5. 3. 4.	Camptonose
XVII.	III. 5. 3–4. 4–5.	Camptonose-auvergnose
XVIII.	IV–V.$_{\text{I.}}$ 3. 1. 1. 4. 3(4).	No name
XIX.	IV.$_{\text{II.}}$ 3′. 1. 1. 2. 3.	Roselandose
XX.	IV(near V).$_{\text{II.}}$ 4. 4. 1. 2(3). 3(4).	No name

It will be observed that normative quartz, varying within wide limits, is noted in all the rocks except one (XIII, andose-camptonose) where it fails entirely. Feldspars compose a large percentage of all the norms, except XVIII and XX, and in most of them they amount to more than 50 per cent. Orthoclase and albite, and anorthite except in XVIII and XX, are always present, and with the exception of XVIII and XX albite and anorthite combined are greatly in excess of orthoclase, indicating plagioclase of soda-lime variety to be the dominant feldspar. The composition of the soda-lime feldspar ranges from labradorite to albite-oligoclase, with the dominant species in most of the rock types andesine usually intergrown with spindles of orthoclase (microcline). It is worthy of note that the salic minerals are dominant at the acid end of the series, with approximately equal amounts of salic and femic minerals in the middle members, while at the extreme basic end femic minerals greatly predominate.

The important femic minerals are of two kinds, (1) ferromagnesian silicates, hypersthene or diopside or both, and (2) ore minerals magnetite, ilmenite, rutile, and apatite with lesser amounts of hematite and pyrite, and in three norms, titanite. Hypersthene is always present though in variable quantity ranging from nearly 8 per cent to 27.50 per cent, while normative diopside occurs in 8 of the 20 norms in usually large amount. Of the ore minerals, ilmenite and apatite are always present, being largest in the more femic magmas, while magnetite varying within wide limits is only absent from three of the norms. Hematite, rutile, titanite, and apatite are present in several of the norms, the first three varying rather widely, while the last (pyrite) is in small amount and is quite uniform.

Norms of ore rocks (nelsonites) Amherst-Nelson counties.

	I	II	III	IV	V	VI	VII	VIII
Quartz	.42	....	....	1.65	....	....	.42	....
Orthoclase	....	....	....	....	....	....	2.78	....
Albite	....	....	....	....	....	....	1.57	....
Corundum	....	....	....	....	....	....	2.65	....
Leucite	....	....	....	....	....	....	....	1.31
Nephelite	....	....	....	....	....	....	....	.57
Hypersthene	.40	....	1.10	....	....	....	1.60	....
Diopside	....	1.79	....	....	....	....	....	....
Olivine	....	....	....	....	....	1.26	....	.70
Ilmenite	9.73	13.22	58.98	49.86	60.65	52.46	31.31	30.10
Magnetite	....	....	....	....	....	....	12.06	19.72
Hematite	2.88	3.68	11.04	15.38	2.72	4.32	35.20	23.04
Rutile	64.56	58.96	11.76	15.20	5.76	9.36	....	....
Apatite	22.18	19.15	16.13	17.81	29.57	30.91	9.74	22.18
Pyrite	.62	3.00	....	....	2.18	2.76	....	....
Water	.20	.56	.73	1.40	.03	.68	2.13	1.17
	100.99	100.36	99.74	101.30	100.91	101.75	99.46	98.79
Less excess CaO					.39			
					100.52			

The first most striking fact to be noted in the annexed table of norms of the nelsonites is, with but few exceptions, the absence of salic minerals, and also of the practical absence of the ferromagnesian minerals among the femic group. Among the salic minerals normative quartz is present in only three of the eight norms and in each in very small amount. Of the feldspars, orthoclase and albite, the former slightly in excess of the latter, and the two combined totaling less than 5 per cent, occur in only one norm (VII). The lenads, leucite and nephelite, are shown in small amounts only in the norm of rock VIII.

Of the ferromagnesian minerals in the femic group, hypersthene is present in the norms of rocks I, III, and VII; diopside in the norm of rock II; and olivine in the norms of rocks VI and VIII. These are present in small amounts, neither exceeding in any case 1.79 per cent.

The norms of these rocks are composed essentially of the ore minerals in the femic group. Ilmenite, apatite, and hematite, varying within wide limits, are always present; ilmenite reaches a maximum of more than 60 per cent, apatite more than 30 per cent, and hematite more than 35 per cent. Rutile, the next most constant constituent, fails in the norms of only two rocks, VII and VIII, and ranges from nearly 6 per cent to more than 64.50 per cent. Normative magnetite occurs only in rocks VII and VIII, but in large amount in each, while pyrite ranging from less than 1 to 3 per cent is present in four of the eight norms (I, II, V, and VI).

MINERALOGICAL CHARACTERS.

INTRODUCTION.

The mineralogical composition of igneous rocks is dependent chiefly upon chemical composition of the magmas and the physical conditions under which they solidified. The chemical composition of the rocks forming the Amherst-Nelson counties region has been discussed on pages 203-213, and the chemical relationships of the different types pointed out. In addition to the chemical characters, there are usually present certain minerals which show more or less common characters that are mineralogically characteristic of comagmatic regions.

The mineralogical evidences of "consanguinity" of the igneous rocks composing the Amherst-Nelson counties region are the presence of a peculiar sky-blue opalescent quartz, the prominence of apatite and the titanium minerals rutile, ilmenite, and in a few places titaniferous magnetite, and of pyroxene (chiefly hypersthene) or its alteration product amphibole (actinolite). Further kinship of the rocks of this region is indicated microscopically by the character of the dominant feldspar being a calcic-soda plagioclase (andesine) with spindle-shaped intergrowths of microcline (orthoclase) (Pl. VIII). Graphite occurs in most of the rock types of the region and in places is an important constituent.

The absence of primary hornblende as a true rock constituent is a distinctive character in the mineral composition of the rocks of the region. That primary hornblende did not develop as a mineral constituent of these rocks can not be ascribed to chemical composition of the magmas, for pyroxene was rather abundantly formed, but to the physical conditions which obtained during the solidification of the magmas.

Quartz.

Quartz is developed in largest amount in the outside quartz monzonite-gneiss and the hornblende facies of the syenite. It is a prominent constituent in places, and is always present but usually in very subordinate amount, frequently only in microscopic proportion, in the feldspathic facies of the syenite. It occurs sparingly in the other rock types, especially gabbro and some nelsonites. In the nelsonites it is limited almost exclusively when present to border positions, especially in the transitional zones of the nelsonites which are marked by gradations into the inclosing syenite.

The quartz has developed uniformly as irregular formless grains, without the slightest indication of crystal outline, and ranges from tiny specks of almost microscopic dimensions up to masses many inches across. It is always fresh and of a peculiar but beautiful sky-blue opalescent color which is its most distinctive feature. Its blue color is apparent even in thin microscopic sections. The most pronounced microscopic character of the mineral is the abundant, closely crowded, minute hairlike or acicular, inclusions of rutile, which are distributed rather unevenly through each grain. The rutile inclusions have higher refraction than the host (quartz), are usually dark in color, and double refraction is not recognizable. They lie at all angles in the quartz grains but sometimes they are arranged in sets of parallel lines which intersect at all angles. These relations are well indicated in Pl. IX, which shows two microphotographs of the same quartz individual but of different magnifications. Other inclusions than rutile are frequently present to some extent in the quartz but they are of minor importance and do not call for description.

Microscopically intergrowths of quartz and feldspar as micrographic structure are rarely or never developed. Plate XVII, fig. 3, shows an intergrowth of quartz and ilmenite similar to graphic structure in some granites. Plate XXXVI, fig. 2, shows an intergrowth of quartz and rutile. Dynamic pressure metamorphic effects are often exhibited in thin sections of the quartz, chiefly in granulation, fractures, and undulous extinction.

In 1885, Mr. Robert Robertson[a] examined chemically and microscopically specimens of the blue opalescent quartz from the Nelson County area with a view to ascertaining the cause of the blue color. He fused a fragment of the mineral before the hot-blast blowpipe flame and found that it retained its blue color. He says: "In view of the color of some varieties of titanic oxide, when seen by reflected light, it appears possible that the partial reflection of light by the surfaces of these microscopic crystals occasions the color in question, or the latter may be in a measure due to interference of light occasioned by these crystals."

In describing a similar sky-blue opalescent quartz developed as phenocrysts in a quartz-feldspar-porphyry from Texas, Iddings states that the color of the quartz "is undoubtedly due to reflections of blue light-waves from the minute colorless prisms, whose width is a fraction of the length of light-waves. It is similar to the blue color of the sky. It is probable, however, that there is also blue light produced by interference of the light reflected from both sides of the minute tabular crystals whose width is also of the order of a fraction of a light-wave length; so that both kinds of phenomena occur within these quartzes."[b]

In 1900, Holland described a blue quartz occurring as a rock constituent in charnockite, a local name given to a hypersthene granite found in India. Like the blue quartz of the Virginia and Texas areas, that from India is crowded with minute hairlike inclusions, presumably rutile, arranged with crystallographic regularity. Concerning the cause of color of this quartz Holland says: "I conclude, therefore, that the hairlike inclusions, to which probably the blue colour of the quartz is due, are arranged with crystallographic regularity . . . ."[c]

It seems probable that the blue color of the quartz characterizing the rocks of the Amherst-Nelson counties area is to be attributed to the multitude of minute hairlike inclusions of rutile as explained by Robertson, Iddings, and Holland.

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[a] Robertson, Robert, An Examination of Blue Quartz from Nelson County, Virginia, The Virginias, 1885, vol. vi, pp. 2-3.

[b] Iddings, J. P., Quartz-Feldspar-Porphyry (Graniphyro Liparose-Alaskose) from Llano, Texas, Jour. of Geology, 1904, vol. xii, p. 227.

[c] Holland, T. H., The Charnockite Series, A Group of Archæan Hypersthenic Rocks in Peninsula, India, Memoirs of the Geological Survey of India, 1900, vol. xxviii, pt. 2, pp. 138-139.

Feldspar.

As is indicated in the chemical analyses and confirmed by microscopic study of thin sections, the rocks of the region are characterized by the development of several varieties of feldspar as rock constituents. Their composition proves that representatives of both the orthoclase and plagioclase groups occur.

Feldspar is most abundantly developed in the feldspathic facies of the syenite, composing more than 90 per cent of the rock mass, and is an essential constituent of the quartz monzonite-gneiss, gabbro, and diabase. It occurs in but is a less important component of the gabbro-nelsonite, and is only occasionally present in the nelsonites.

Intergrowths of the feldspars are characteristic of the quartz monzonite-gneiss, syenite, and gabbro. In the gneiss and to a less extent syenite and gabbro, the intergrowths are of orthoclase with plagioclase as true microperthite, but the common form of feldspar intergrowth in the syenite and gabbro is of a different kind. It consists of andesine as the host with irregular, intergrown spindle-like bodies of orthoclase (microcline) (Pl. VIII, figs. 1 and 2). Intergrowths of feldspar with quartz as micropegmatite are developed in the quartz monzonite-gneiss but are essentially absent in the other rock types. Lack of development of zonal structure characterizes alike the feldspar of all the rock types of the region. Micropoikilitic texture is common. The feldspars always carry inclusions which are frequently so abundant and closely crowded, especially in the feldspar of the syenite, as to almost completely mask the feldspar substance. The principal inclusions are colorless and transparent crystallites of greatly elongated prismatic and tabular habits of feldspar to those of irregular outline. These are sometimes arranged along definite parallel lines, but more often they are distributed entirely without crystallographic regularity. These inclusions form a nearly constant microstructure of the feldspars. Inclusions of other kinds usually common to feldspars occur but they do not merit special description.

Orthoclase as separate anhedral grains and as spindle-like intergrowths in plagioclase (chiefly andesine) is a constituent of all the rocks in which feldspar occurs, but is least in the diabases and is rare in the nelsonites. In every rock type where it enters as an important constituent it is subordinate to plagioclase, the ratio ranging from approximately 1:2 to 1:5 of orthoclase to plagioclase.

Microcline is sometimes developed though always subordinate in amount to orthoclase in the quartz monzonite-gneiss, and forms abundant spindle-like intergrowths in plagioclase (andesine) of the syenite. Like orthoclase it is always developed in anhedral form.

Plagioclase, of which there are several species present, is the dominant feldspar in every rock type in which this group enters as a rock component. As stated above the orthoclase and plagioclase molecules entering into the composition of the feldspathic constituent of the rocks vary from approximately $Or_1(AbAn)_2$ to $Or_1(AbAn)_5$. The composition of the plagioclase, especially the dominant species, varies in a general way according to the rock type, although several species may be developed in the same rock. The range in composition is from labradorite to albite. Corresponding to composition the chief plagioclase in each rock type is: Quartz monzonite-gneiss, oligoclase near andesine; syenite, andesine; gabbro, andesine; diabase, labradorite; gabbro-nelsonite, basic andesine near labradorite.

In all the rock types in which feldspar enters, except diabase, plagioclase is developed in anhedral forms, sometimes approaching irregular tabular or roughly prismatic forms, but without crystal boundaries. In the diabases the plagioclase ranges from anhedral (equant) to elongated lathlike forms. Twinning according to the albite law is the rule for the plagioclase observed in each rock type.

Pyroxene (Hypersthene).

Orthorhombic pyroxene, hypersthene, is the most characteristic one of the original mafic silicate minerals of the region. Hypersthene or its alteration product amphibole (uralite) is an essential mineral in the border facies of the syenite, gabbro, gabbro-nelsonite, and occasionally the nelsonites. In the diabases hypersthene is replaced by the monoclinic pyroxene, augite. Secondary amphibole derived from hypersthene is more abundant in some of the rocks, especially locally, than the original orthorhombic pyroxene. The alteration of the pyroxene to amphibole is described on page 220.

The color of the hypersthene in thin sections is somewhat variable, ranging from pale yellow and green to reddish tints, the latter being probably the most characteristic. Pleochroism is likewise subject to some variation though always readily perceptible. The optical properties of the mineral and a chemical analysis showing its composition are given on page 218. The mineral is frequently characterized by brown inclusions as plates, irregular rods and grains, which are often arranged with definite regularity in the hypersthene. The mineral is never developed in euhedral crystals but usually occurs in anhedral forms, and less often subhedral.

Composition and optical properties.—A specimen of this mineral from the syenite of the American Rutile Company's quarries near Roseland, could not be secured for analysis, as apparently all of it had altered to amphibole (actinolite). However, enough of the mineral occurring in the same rock at the General Electric Company's mine near Rose's Mill was isolated and freed from the alteration rims of amphibole, and analyzed with the following results:

Analysis and ratios of hypersthene from the General Electric Company's mine, Nelson County.

(WM. M. THORNTON, JR., *Analyst.*)

	Per cent.	*Ratio.*
SiO_2	52.44	.874
Al_2O_3	3.51	.034
Fe_2O_3	1.46	.009
FeO	17.11	.238
MgO	16.73	.418
CaO	2.98	.054
Na_2O	0.26	.005
K_2O	1.24	.013
H_2O-	0.18	
H_2O+	1.96	
TiO_2	0.94	.011
MnO	0.52	.007
P_2O_5	0.05	.001
S	Trace	
Total	99.38	

The ratio of $FeO:MgO = 1:1.76$; if CaO be included with MgO the ratio then becomes 1:2. The percentages of Fe_2O_3 and Al_2O_3 shown in this analysis are usual in analyses of hypersthene, the latter (Al_2O_3) being sometimes present up to 10 per cent. The K_2O ranges a trifle high for hypersthene.

The optical properties of the mineral as determined by Dr. E. S. Larsen, show it to be an orthorhombic pyroxene of a variety rich in iron (hypersthene). The obtuse bisectrix Z is parallel to the crystallographic axis c, and the mineral is optically negative (—). Pleochroism is perceptible: X = pale pink, Y = pale yellowish-green, Z = pale green. The indices of refraction measured by the immersion method are:

$$\alpha = 1.696 \pm 0.003, \ \beta = 1.710 \pm 0.003, \ \gamma = 1.713 \pm 0.003.$$

The measurements of the birefringence with the Babinet compensator are: $\gamma - \alpha = 0.017, 0.017, 0.018, 0.0185$, average 0.018; $\gamma - \beta = 0.0036$.

The axial angle as measured with the Federof stage gave values of 2V = 53°, 54.1°, 52.4°, 52.1°, 52°, 54.2°; average 53.0±° 1°. The axial angle computed from the birefringence $\sin^2\gamma = \frac{\gamma - \beta}{\gamma - \alpha}$ is 53.2°. Dispersion is barely perceptible, $\rho > V$.

Amphibole (Uralite).

Compact pyrogenetic amphibole has not been identified in thin sections of any of the rocks of the region, but fibrous uralite having the composition of actinolite and derived from orthorhombic pyroxene (hypersthene) is a common, and at times abundant, constituent of all the rocks, except the quartz monzonite-gneiss. It is developed in minute grains up to very large masses locally abundant in the border facies of the syenite. Its optical properties and a chemical analysis showing its composition are given on page 219. As described and discussed on page 220, the alteration of hypersthene in the rocks to uralite of actinolite composition is not one of simple paramorphism but has been accompanied by marked chemical changes.

Composition and optical properties.—An analysis of hornblende separated from the rock in the south cut of the American Rutile Company's quarries, near Roseland, yielded the following results:

Analysis and ratios of hornblende from Nelson County.

(WM. M. THORNTON, JR., *Analyst.*)

	Per cent.	*Ratio.*
SiO_2	51.31	.855
Al_2O_3	None	
Fe_2O_3	5.31	.033
FeO	10.12	.140
MgO	17.93	.448
CaO	10.95	.195
Na_2O	0.22	.003
K_2O	0.29	.003
H_2O-	0.04	
H_2O+	1.26	
TiO_2	3.00	.037
MnO	0.11	.001
P_2O_5	None	
CO_2	Trace	
Total	100.54	

As computed from this analysis the ratio of CaO: (Mg,Fe)O is 1:3 and corresponds to actinolite, which is further confirmed by the optical properties given below.

Megascopically the mineral is green in color and has rather dull lustre except on the fracture surface. The cleavages are not easily seen in hand specimens on account of the fine fibrous character of the mineral, but large lustrous, slightly curved fracture surfaces resembling cleavage, are prominent. Sections cut parallel to this surface exhibit most of the fibres parallel to 100 and show the emergence of the acute bisectrix.

In normal thin sections the mineral is colorless but in thicker slices it is green and pleochroic. The mineral shows the usual cleavage of amphibole and the fibres manifest a tendency to orientation. Oriented rods of a reddish-brown to opaque material give the effect of shading to the section. These rods are usually parallel to the fibres but cut across the fibres not oriented and probably represent cleavage cracks in the original mineral. Material for obtaining good basal sections was not procurable so that their orientation in this direction is not known.

The fine powder immersed in a liquid of the same index of refraction showed many fragments with parallel extinction cut at a small angle to the acute bisectrix. The extinction angle measured on ten cleavage flakes gave values ranging from 18.4° to 16°, with an average of 17.4°. The extinction angle on a section parallel to the plane of the optic axis is 18°. The dispersion is strong and complete extinction does not occur. The indices of refraction measured by the immersion method are: $\propto = 1.620 \pm 0.003$, $\gamma = 1.649 \pm 0.003$, $\gamma - \propto = 0.029$.

The birefringence was measured directly by measuring the thickness of oriented sections and comparing the interference color with those of the table given by Iddings. The average of 7 measurements gave $\gamma - \beta = 0.0123$ with values varying from 0.0115 to 0.0128, $\beta - \propto = 0.0176$, $\gamma - \propto = 0.0310$. The axial angle was measured on five pieces cut nearly normal to the acute bisectrix and gave values ranging from 79.7° to 82°, with an average of 81°. The axial angle computed from the values found for the birefringence gave 79.6°, which is within the limits of probable error.

The dispersion of the optic axis is strong and the mineral is optically negative (—); the optical orientation is that of actinolite.

Uralitization (alteration of hypersthene to uralite).—The chemical and microscopical studies of the syenite, as well as of other rock types of the region, conclusively prove that the amphibole (actinolite) is secondary and has been derived from the original mineral, hypersthene, subsequent to the solidification of the rock. Not only is this change apparent in thin sections under the microscope where nearly all stages of alteration from incipient change to complete transformation of hypersthene to amphibole, can be traced, but it is clearly shown in some of the hand specimens, where large and small cores or eyes of hypersthene are rimmed by an irregular but usually deep border of amphibole (Pl. VII, and fig. 15).

The hornblende is fibrous actinolite and not the compact variety which has been ascribed by most petrographers to paramorphic alteration of augite[a] and which, according to Iddings and others, has not been conclusively proved to be alteration, but can in some cases at least be attributed to synchronous growth. In this case the rock has suffered intensely from dynamic forces under deep burial, and idiomorphic compact hornblende has not been observed.

On comparing the analysis of the original hypersthene (page 218) with that of uralite (actinolite, page 219), the most important changes noted in the essential constituents are the oxidation of ferrous to ferric iron, slight increase in magnesia, and a large addition of lime. It seems reasonably certain that the source of the additional lime involved in this change was derived from the lime-soda feldspar, which is present in large amount and is the principal feldspathic constituent in the rock (Pl. VIII, fig. 1).

Plate VII is a photograph, natural size, of a polished specimen of the syenite from the General Electric Company's mine, and the sketch, fig. 15, made partly from the same specimen, illustrate the formation of the amphibole (actinolite). The unaltered pyroxene (hypersthene) is dark brown to bronze in color and forms the cores of the larger masses of amphibole, which form an outer fibrous zone of silky lustre, and extends into the feldspar along cleavage planes and fractures, giving the irregular lines noticed in the photograph. The alteration is probably due to the circulation of solutions along almost microscopic fractures, since most of the hornblende masses are connected by them. It seems clear that the feldspar has furnished a part of the material entering into the formation of the hornblende, for where the fractures pass through the feldspar hornblende has developed, and they form markedly dark green lines ranging up to 2 mm. in width, but where the fractures cross the blue quartz no alteration has taken place and they are almost invisible.

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[a] For a discussion "On the paramorphic alteration of pyroxene to compact hornblende" see Gordon, C. H., Amer. Geologist, 1904, vol. xxxiv, pp. 40-43. References to the literature are cited by Gordon.

The chemical analyses clearly indicate that the change from hypersthene to actinolite was not one of paramorphism but involved chemical changes described above in the transformation. The change is a deep-seated one as is fully indicated by the character of the rock already described. According to Van Hise[a] the change of orthorhombic pyroxene to hornblende is accompanied by diminution of volume and absorption of heat.

Biotite.

This mineral is an important constituent of the quartz monzonite-gneiss and some of the nelsonites. It is rare though not entirely absent in the other rock types of the region. In some instances its relations are such as to suggest probable secondary origin, but in most cases it is undoubtedly a primary constituent. The color is uniformly brown, with marked pleochroism, and it presents no unusual features.

Olivine.

While olivine is met with as a constituent in some of the diabases including basalt, it is in nowise characteristic of the region. It exhibits the usual features and since it is not a characteristic mineral of the region it does not call for further comment.

Apatite.

This mineral is observed either as an essential or subordinate constituent in all the rocks of the region. It is developed megascopically, though very unequally in amount, in each type except the quartz monzonite-gneiss and diabase, in which it occurs only in minute microscopic crystals, frequently of sharp idiomorphic outline. It forms an essential mineral in the gabbro-nelsonites and nelsonites proper, and in all other types it is developed only as a minor constituent.

It has occasionally been noted in fairly large masses in the syenite, and is fairly uniform in size but variable in quantity in the nelsonites, averaging 2 to 3 mm. in cross-section. Quantitatively the range in apatite in the rocks is from 0.3 per cent up to 30 per cent. The mineral is developed in euhedral and anhedral forms with an almost constant tendency towards crystal outline. It exhibits the usual optical properties, but in many of the nelsonites it shows partial alteration to the earthy form osteolite. It is a fluor-apatite containing at times a little chlorine. This is in accord with the nelsonites in general as shown in the table of analyses of the rocks on page 147.

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[a] Van Hise, C. R., A Treatise on Metamorphism, Mono. xlvii, U. S. Geol. Survey, 1904, pp. 270-271.

A chemical analysis of apatite from one of the segregated masses occurring in the nelsonite of the General Electric Company's mine, and given on page 108, is as follows:

Analysis of apatite from nelsonite, General Electric Company's mine, Nelson County.

(WM. M. THORNTON, JR., *Analyst.*)

	Per cent.
CaO	54.37
MgO	0.53
P_2O_5	41.30
F	2.50
Cl	0.10
SiO_2	0.33
TiO_2	0.20
Fe_2O_3	0.61
H_2O	0.19
	100.13
Excess oxygen	1.07
	99.06

The melting point of the apatite represented by this analysis was determined by the Bureau of Standards to be 1,645° C.

Magnetite.

Magnetite is developed as a minor accessory constituent in most of the rock types of the region. It is essentially absent from the feldspathic facies of the syenite but it forms one of the lesser modal components of the region. It is developed as a principal constituent of the magnetite-biotite varieties of nelsonite and at times is quantitatively the most abundant mineral. The mineral occurs chiefly as irregular grains, sometimes in well-developed crystals, and usually contains more or less titanic oxide. It exhibits no unusual features and needs no special description.

Ilmenite.

In abundance ilmenite is one of the characteristic minerals of the region. Its general characters are similar to those of its many occurrences elsewhere, except that it is never developed here in large granular masses, but is mostly in irregular small grains rarely exceeding several mm. in cross-section. It forms the dominant constituent in most of the nelsonites, amounting in some instances to as much as 80 per cent of the entire rock mass, when it forms a background in which lie the other minerals. The mineral is a prominent component of the gabbro-nelsonites, and is an important though accessory constituent of the gabbros and the hornblendic facies of the syenite, as exposed in the quarries of the American Rutile Company near Roseland.

As remarked above one of its characteristics is development in equidimensional grains of usually irregular outline, and not exceeding in size the other chief constituents of the rock in which it occurs. A second important feature of the mineral is its composition. In addition to ferrous oxide it always contains a considerable percentage of ferric oxide, less than 1 per cent of vanadium, and a much smaller amount of chromium. As developed in the discussion below of the chemical composition of the ilmenite, the mineral appears not to be a straight ilmenite ($FeO.TiO_2$) nor does it correspond to the formula $FeO.TiO_2.nFe_2O_3$ as suggested by some authors for many occurrences of the mineral. Theoretically the mineral of this region corresponds in composition to a titanate of ferrous and ferric oxides ($FeO.TiO_2$ and $Fe_2O_3.nTiO_2$).

The order of crystallization of the ilmenite from the magma in the nelsonites is regarded as essentially contemporaneous with the other constituents with which the ilmenite is associated, since each mineral contains inclusions of the other as disclosed in the microscopic study of thin sections. The ilmenite always appears fresh in the hand specimens but most of the thin sections show more or less alteration of the mineral to leucoxene under the microscope.

Composition of the ilmenite.—An analysis of the ilmenite (I) separated from the rock ilmenite nelsonite of the General Electric Company's mine, and of the same mineral (II) separated from the syenite of the American Rutile Company's quarries, near Roseland, yielded the results given in the annexed table. These two analyses of ilmenite from Nelson County are compared with one of the same mineral (III) from the ilmenite-rutile area in Goochland and Hanover counties, Virginia.

Analyses and ratios of ilmenite from Nelson and Goochland counties, Virginia.

	I		II		III	
	Per cent.	*Ratio.*	*Per cent.*	*Ratio.*	*Per cent.*	*Ratio.*
TiO_2	54.44	.680	50.92	.636	51.83	.648
FeO	40.94	.569	39.40	.547	46.22[a]	.642
MnO	0.52	.007	.....	....	.....	....
Fe_2O_3	4.26	.027	9.17	.057	.....	....
SiO_2	0.34	....	.....	....	2.31	.038
Cr_2O_3	0.07	....	n. d.	....	.....	....
V_2O_5	0.29	....	n. d.	....	.....	....
SnO_2	Trace	....	.....	....	.....	....
Cb_2O_5	None	....	.....	....	None	....
Ta_2O_5	None	....	.....	....	None	....
H_2O	None	....	.....	....	None	....
Total	100.86	....	99.61	....	100.36	....
Specific gravity, 4.713.						

[a] Calculated as FeO.

I. Ilmenite separated from nelsonite, General Electric Co.'s mine, Nelson County. Wm. M. Thornton, Jr., analyst.
II. Ilmenite separated from syenite, American Rutile Co.'s quarries, Nelson County. B. F. Beard, analyst.
III. Ilmenite collected by F. L. Hess from ilmenite-rutile area, Goochland County. R. C. Wells, analyst.

The melting point of ilmenite represented in analysis I, as measured by the Bureau of Standards, is 1,390° C. The analyses in columns I and II indicate that the ilmenite is not uniform in composition, there being a large percentage of Fe_2O_3 present in each case. In view of this circumstance the formula usually applied to normal ilmenite ($FeO.TiO_2$) does not correspond to the two analyses of the mineral given here. If, however, the Fe_2O_3 in each case be changed to the corresponding amount of FeO and added to that found on analysis, the total FeO and TiO_2 approximate closely the formula $FeO.TiO_2$. In view of the considerable amount of Fe_2O_3 found on actual analysis the statement above is without value and does violence to the methods usually employed in calculating mineral formulæ from chemical analyses.

Neither does the general formula for ilmenite ($FeTiO_3.nFe_2O_3$) correspond to the mineral represented by analyses I and II, since there is found in each case an excess of TiO_2 over that necessary to satisfy all the FeO in the formula $FeO.TiO_2$. Of this excess of TiO_2 shown to be present on analysis only the smallest fraction of 1 per cent can be accounted for as admixed rutile which, for one cause or another, could not be separated from the samples of ilmenite analyzed.

Metallographic study of polished surfaces of the Nelson County ilmenite was not attempted, and the Fe_2O_3 present in the mineral may be explained on the basis that the ilmenite is not homogeneous in structure but is composed of intergrowths of hematite (Fe_2O_3) with ilmenite ($FeTiO_3$) and the two not mixed isomorphously as has been assumed for many ilmenites. In his investigations of the ilmenite rocks near St. Urbain, Quebec, Canada, Warren[a] adduces facts which point strongly to the conclusion that the Fe_2O_3 is present as hematite in intimate crystallographic intergrowth with ilmenite.

Theoretically the analyses (I and II) of the table conform to a titanate of ferrous and ferric oxides, and the composition of ilmenite as calculated from these analyses is essentially as follows:

I. 87.55 per cent of ferrous titanate (ilmenite), $FeO.TiO_2$.
12.96 per cent of ferric titanate, $Fe_2O_3.4TiO_2$.

II. 83.14 per cent of ferrous titanate (ilmenite), $FeO.TiO_2$.
16.53 per cent of ferric titanate, $Fe_2O_3.1.6TiO_2$.

We have not found ferric titanates corresponding to $Fe_2O_3.4TiO_2$ and $Fe_2O_3.2TiO_2$ described in the literature, but recently Palmer[b] described the intermediate one $Fe_2O_3.3TiO_2$ under the new mineral name *arizonite.*

The mineral specimen represented by analysis I of the table was subjected to a careful chemical study to ascertain the presence of rare elements. It is of interest to note the presence of an appreciable amount of vanadium with less chromium and a trace of tin. Columbium and tantalum were not detected. In this connection the analyses of rutile from the same area (page 227) which show the presence of both vanadium and chromium should be compared with the analysis of ilmenite in column I.

The exact form or combination in which vanadium and chromium exist in the ilmenite is not known, but possibly in this case as V_2O_3 and Cr_2O_3 replacing a part of the Fe_2O_3.

Rutile.

Like ilmenite the occurrence of large amounts of free titanic oxide in the form of the primary mineral rutile in the rocks is one of the most characteristic features of the region. Its prominence in this region is destined to play an important rôle in petrography, especially in its classificatory relations in the new quantitative system.

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[a] Warren, Chas. H., The Ilmenite Rocks near St. Urbain, Quebec; A New Occurrence of Rutile and Sapphirine, Amer. Jour. Sci., 1912, vol. xxxiii, pp. 265-267.

[b] Palmer, C., Arizonite, A Metatitanate, Amer. Jour. Sci., 1909, vol. xxviii, pp. 353-356.

Apart from its importance commercially and as a rock-making constituent rutile occurs in great abundance as needlelike inclusions in the quartz developed in the rocks, imparting a peculiar but distinctive blue opalescent color to the quartz, which has already been shown to be a prominent and to the unaided eye conspicuous clan character of the region.

As a principal constituent rutile occurs in the rutile nelsonites as irregular equant grains up to 3 mm. in size and may form 65 per cent of the rock mass. It is a prominent mineral in places in both the feldspathic and hornblendic facies of the syenite and is distributed through the rock as formless grains of variable size and in wavy lines or streaks, the percentage of which is very variable. This mineral has nowhere been observed megascopically with crystal boundaries but is always characterized by irregular outlines. The important megascopic and microscopic properties of the mineral are described in detail under the several rock types in which it forms an important constituent.

The composition of both the syenite and nelsonite rutiles is shown in the complete chemical analyses of the mineral given below. Like the ilmenite the analyses of the two rutiles show appreciable amounts of vanadium and chromium, and in each vanadium is much in excess of chromium. The possible effect of these on color of the rutile is discussed below on pages 228-229.

Analyses of the syenite and nelsonite rutile, Nelson County.

(WM. M. THORNTON, JR., *Analyst.*)

	I	II
TiO_2	95.71	98.80
FeO	2.35	1.68
SiO_2	0.92	0.26
V_2O_3	0.15	0.20
Cr_2O_3	0.02	0.07
SnO_2	Trace	None
Cb_2O_5	None	None
Ta_2O_5	None	None
	99.15	101.01
Specific gravity	4.196	4.21

I. Rutile from feldspathic facies of syenite, American Rutile Co.'s quarries, Roseland.

II. Rutile from nelsonite, General Electric Co.'s mine, 1.5 miles northwest of Rose's Mill.

Determination of the melting point of the two rutiles by the Bureau of Standards gave I (syenite rutile) 1,690° C., II (nelsonite rutile) 1,700° C. Both tantalum and columbium were carefully looked for chemically in the two rutiles but were not detected. Neither were they present in the ilmenite. Since the rocks containing these minerals, rutile and ilmenite, are of igneous origin, their similarity in composition with respect to the lesser rare elements is suggestive.

The possible effect of vanadium on the color of rutile.[a]—There are presented in tabular form below determinations of V_2O_3, Cr_2O_3, and FeO in three rutiles which differ strongly in color.

Partial chemical analyses of rutile.

(Wm. M. Thornton, Jr., *Analyst.*)

	I	II	III
V_2O_3	0.15	0.20	0.55
Cr_2O_3	0.02	0.07	0.39
FeO	2.35	1.68	0.81

I. Red rutile from feldspathic facies of syenite, Roseland, Nelson County, Virginia.
II. Very dark rutile from nelsonite on Warwick tract, 1.5 miles northwest of Rose's Mill, Nelson County, Virginia.
III. Nearly black rutile from kragerite, Kragerö, Norway.

Attention has already been directed in the analyses to the predominance of vanadium over chromium. Hasselberg[b] found for the rutiles he examined that when vanadium was present in very appreciable amount chromium was also present, but when vanadium was present in very small amount chromium was present either in trace or entirely absent. Although there are frequent exceptions vanadium is commonly though but slightly in excess of chromium in the known analyses of titaniferous magnetites.[c] The exact form or combination in which these two constituents are present in rutile is entirely conjectural.

It is suggested that for the partial chemical analyses of the rutiles tabulated above, that the difference in color, whether red or nearly black, is probably not to be attributed to iron oxide. In comparing the percentages of iron (FeO) with those of vanadium (V_2O_3) in the table above it will be observed that vanadium increases with decrease of iron, and the color increases with depth in the same direction. In other words, the rutile (I) containing highest FeO and lowest V_2O_3 is red in color, while the rutile (III) showing least FeO and highest V_2O_3 is nearly black; II is intermediate in color and shows less FeO and more V_2O_3 than I. These results are at least suggestive and it will be of interest to ascertain whether the possible relation holds in future analyses of rutile.

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[a] Watson, Thomas L., Vanadium and Chromium in Rutile and the Possible Effect of Vanadium on Color, Jour. Wash. Acad. Sci., 1912, vol. ii, pp. 431-434.

[b] Hasselberg, B., Astrophysical Journal, 1897, vol. vi, pp. 22-26; also Chem. News, 1897, vol. 76, pp. 102-104.

[c] Walz, Isidor, Amer. Chemist, 1876, vol. vi, pp. 453-456; Kemp, J. F., 19th Ann. Rept. U. S. Geol. Survey, pt. III, 1897-8, pp. 387-397.

It is a noteworthy fact that of the 22 analyses of rutile quoted by Hintze[a] neither vanadium nor chromium is reported as being present in a single analysis. Sufficient work has been accomplished by recent students, however, to indicate that in future analyses of rutiles careful search should be made for both vanadium and chromium.

Graphite.

Graphite is noted as a minor constituent in places in most of the rocks of the area, but more especially in association with the basic rock types, nelsonite and gabbro. It is most abundant in the General Electric Company's mine on Piney River, where it occurs as a prominent constituent in the gabbro, and locally in the syenite, averaging about 2 mm. in diameter arranged in parallel flakes which impart a gneissic appearance to the rock. In many instances it is noted as microscopic inclosures in the rock-forming minerals of several rock types occurring in the district. In one or two cases it is found in the blue opalescent quartz of veinlike character in the rocks. Other occurrences are noted under Miscellaneous Minerals on page 232.

The graphite is frequently intimately associated with pyrite, sometimes suggesting the relations of intergrowths, which make it necessary to regard the two minerals as contemporaneous in origin. Such marked association of the two minerals undoubtedly indicates that they are in some way genetically related. It is possible and even probable that they have undergone some rearrangement on concentration from metamorphism, a feature so strongly marked in the rocks of the district. Under the conditions of rearrangement or concentration pyrite might readily have been precipitated in part by the graphite.

In summary it may be stated that sedimentary origin of the graphite is regarded as untenable since the rocks of the district are igneous. Neither carbonaceous nor other sedimentary beds are known in the district.

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[a] Hintze, C., Handbuch der Mineralogie, 1907, p. 1622.

The graphite occurs disseminated in the rocks and not in veins. In view of these facts, the mineral in the rocks of this district must be regarded as of magmatic origin.

Other Minerals.

The practical absence of primary hornblende in the rocks of the region is a very noteworthy feature. Secondary hornblende derived chiefly from pyroxene (hypersthene) is an abundant constituent, but with the exception of the single occurrence of hornblende nelsonite near Lovingston, primary hornblende has not been observed in any of the rocks.

Among the lesser minerals may be mentioned the sulphides, pyrite and pyrrhotite. The former (pyrite) occurs both as a minor constituent chiefly of the nelsonites and coating the surfaces of joint-planes. In the latter occurrence it is certainly of secondary formation, and its relations are such in some instances as to indicate probable secondary formation in its occurrence as a rock component. Pyrrhotite has been observed as a subordinate mineral in several of the rock types, chiefly as shapeless grains and is probably an original or primary mineral.

Titanite occasionally occurs as sporadic crystals and grains in some of the basic rocks, and zircon has been observed in a few cases in several thin sections of the syenite.

TEXTURAL CHARACTERS.

The textural characters of the rocks of the region point to the physical conditions under which the magmas solidified rather than dependence on chemical composition. The rocks are entirely holocrystalline and their granularity conclusively shows that with possibly one or two exceptions (chiefly dikes of diabase or basalt) they solidified at depth and are plutonic. No effusive types occur.

The even-granular texture predominates, although porphyritic texture is frequently observed in the quartz monzonite-gneiss, gabbro-nelsonite, and in some of the nelsonites. In the quartz monzonite-gneiss and gabbro-nelsonite the phenocrysts are feldspar; in the porphyritic facies of nelsonites, apatite.

AGE RELATIONS.

There is no direct evidence upon which to base an accurate or even a close determination of the age of the rocks of the district. The principal facts for regarding the district mapped as a comagmatic region have been stated and discussed. Five principal rock groups have been recognized and described, which, named in their probable order of differentiation, including the surrounding rocks, are: (1) Biotite-quartz monzonite-gneiss with schists, (2) syenite, (3) gabbro, (4) nelsonite, and (5) diabase. Several of these are regarded as approximately contemporaneous, since gradations between them have been established. The oldest of these is the quartz-biotite monzonite-gneiss, and the youngest diabase, since the latter cuts all other rock types in the district.

The quartz-biotite monzonite-gneiss is the dominant type of the southeast slope of the Blue Ridge and southeastward along its base, in middle western Virginia. Just beyond the southeast limits of the mapped area is an extensive belt of Lower Cambrian rocks, the lowest members of which have been formed from detritus derived from the quartz-biotite monzonite-gneiss. The evidence seems conclusive, therefore, that the gneiss at least, which is the country rock of the region mapped, is pre-Cambrian. Until more conclusive evidence can be found, which must be sought beyond the limits of the area mapped, the remaining rock types, with probably the exception of diabase, must likewise be regarded as pre-Cambrian.

The diabase is undoubtedly later in age than the other rocks in the district, since it has been found cutting them, and probably much later, as the joints in several of the other types have guided its intrusion in part at least.

MISCELLANEOUS MINERALS.

INTRODUCTORY STATEMENT.

Under this heading are included (a) certain minerals occurring within the limits of the mapped area but not described in the preceding pages of this report, and (b) several minerals occurring in the same general region but beyond the limits of the area mapped.

MINERALS OCCURRING WITHIN THE MAPPED AREA NOT PREVIOUSLY DESCRIBED.

Sphalerite.—It is reported that several years ago a shaft was sunk in the bed of Allen Creek half a mile southwest of Rose Union on a vein carrying the admixed sulphides, sphalerite, pyrite, and galena. When the locality was visited by the writers the shaft had been filled, but pieces of the ore said to have been taken from the vein were found near the old shaft. The ore, as indicated by these fragments, is composed largely of fine-granular, light brown sphalerite, admixed with a little pyrite, and perhaps galena in quartz gangue. The quartz contains small cavities in which there are a few imperfectly formed quartz crystals. The vein is probably too small to be of commercial value.

Galena.—Near the top of the ridge, 2.25 miles southeast of Massie's Mill, a quartz vein is exposed on the side of an old caved tunnel. It is lenticular in shape varying from about one foot at the surface to four feet at a depth of 15 feet; dip is 70° S. 50° E. It is reported to carry galena but only a little oxidized pyrite could be found in the quartz on the dump. A number of pieces of white quartz carrying galena have been found on the ridge half a mile to the southwest. It is not likely that these deposits are of any economic value.

Graphite.—Graphite occurs in limited amount in most of the rocks and at many places in the area. A small vein of graphite is reported to have been opened on the west side of Hat Creek, 2 miles above Bryant, but the pits were filled when the district was visited by the writers. The largest quantity of graphite was found in the General Electric Company's mine and in the rocks in that vicinity, particularly on Allen Creek. These occurrences are described in part on pages 229-230. A thin section cut from the hand specimen taken from a rock composed chiefly of graphite and pyrite, found on the north bank of Allen Creek, indicates that the two minerals are in intimate relationship. Pyrite is more abundant than graphite, which is distributed through the pyrite in irregular areas of varying size, and as stringers and flakelike masses. The relations are somewhat uncertain of exact interpretation but the pyrite is possibly later than the graphite. It is doubtful if any of the graphite occurs in quantities sufficiently concentrated to pay for working.

Kaolin.—Kaolin is one of the important mineral resources of the district and must be considered in any economic report on the area, but in this bulletin it will not be possible to give more than a brief description of its occurrence, the detailed statement being reserved for a future publication of the State Survey on the clay deposits of the Piedmont Plateau province.

All clays found within this area are residual clays resulting from the decomposition of rock in place. The iron-bearing minerals of the syenite are segregated near the borders of the area, leaving the central portions essentially free from such minerals, as is shown by the white clay soil, which is a very conspicuous feature in a region where red clays are the rule. Quartz is not so prominent a constituent of the syenite composing much of the central area, and over large sections it is only present in very small quantity. Auger borings were made in several places and samples obtained that were free from grit and very plastic. Some of this kaolin is suitable for the manufacture of white-ware products and with better transportation facilities should prove of great economic importance as the quantity is unlimited.

In 1890, the Pittsburg Kaolin Company[a] began mining kaolin from open cuts on the west side of Possum Trot Branch about one mile a few degrees west of north from Roseland Post-office. A mill was erected at a reported cost of $50,000 for preparing the product for market, which was used as a filler in the manufacture of paper. Operations extended over a period of about 5 years when they were suspended on account of litigation among the stockholders, and have not been resumed since.

MINERALS OCCURRING BEYOND THE LIMITS OF THE MAPPED AREA.

Allanite and sipylite.—The rare minerals allanite, a silicate, and sipylite, a niobate of the rare-earth metals, have been found in some quantity on the Friar Mountain near Piney River about 4 miles northwest of Lowesville. Very little exploration work has been done but the minerals are found associated with pegmatite dikes. They are of little value except for their rarity and are mostly sold to museums and mineral dealers.

Our knowledge of the Amherst County, Virginia, sipylite is due to the careful investigations of Dr. J. W. Mallet,[b] who described the mineral as occurring at the northwest slope of Little Friar Mountain, adhering to and imbedded in allanite. An analysis of the mineral from this locality by W. G. Brown is given in Dana's System of Mineralogy (page 731).

Cassiterite (tin ore).—The Irish Creek tin area of Rockbridge County is located about 10 miles west of the area mapped and described in this report. Cassiterite (tin ore) occurs principally in greisen veins, which traverse the inclosing granite in all directions, and have steep but varying dips. The veins are usually narrow, measuring as a rule less than a foot in thickness, although a width of several feet has been noted. The associated minerals include wolframite, arsenopyrite, pyrite, and beryl. In addition to these siderite, limonite, chlorite, muscovite, damourite, and fluorite have been reported.

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[a] Watson, Thomas L., Mineral Resources of Virginia, 1907, p. 172.

[b] Mallet, J. W., Amer. Jour. Sci., 1877, vol. 14, p. 397; ibid., 1887, vol. 22, p. 52.

Ferruginous Conglomerate.

Boulders of ferruginous conglomerate were found at two places within the area mapped; one locality is 100 yards north of Maple Run and 2 miles southeast of Lowesville, the other is 1.25 miles east of Rose Union, near Tye River, but about 30 feet above the lowlands bordering the river. In both places the conglomerate consists of gravel subangular to rounded, ranging up to 3 inches or more in diameter, and firmly cemented together by limonite which has been deposited around the sand and gravel. The larger pieces of gravel are derived from the syenite and contain feldspar and blue quartz. The smaller fragments are more angular in shape and consist for the most part of blue quartz, ilmenite, and a little rutile.

GEOLOGY OF THE ORE-DEPOSITS OF THE ROANOKE COUNTY AREA.

LOCATION AND TOPOGRAPHY.

The Roanoke ilmenite-apatite area[a] is located in Roanoke County about 2 miles east of Vinton and 4 miles east of Roanoke City, as shown on the accompanying map, fig. 19. It lies on the basal slope and near the

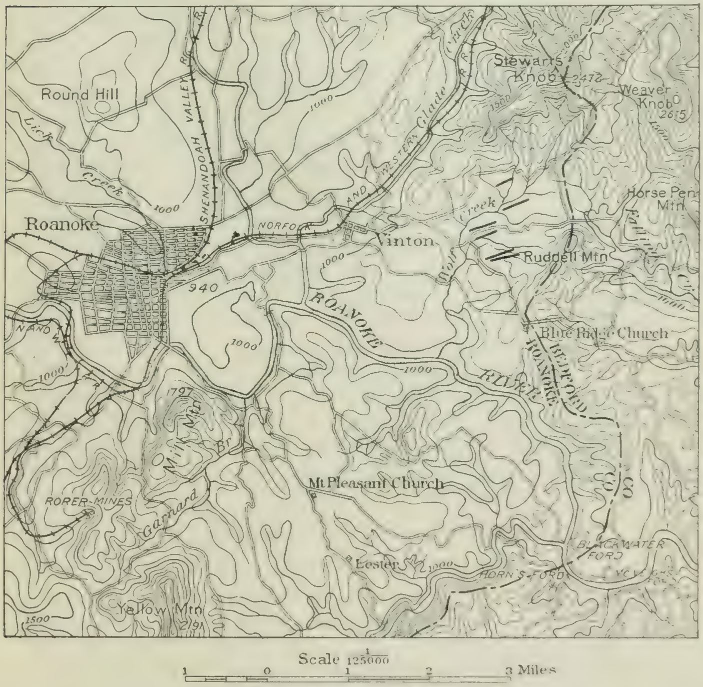

Fig. 19.—Topographic map of a part of Roanoke County, Virginia, showing location of nelsonite dikes 4 miles east of Roanoke City. (Based on the Roanoke sheet of the U. S. Geol. Survey.)

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[a] The first published statement on the ilmenite-apatite deposits of this area, though brief, was by the senior writer in "Mineral Resources of Virginia," 1907, pp. 301-302.

foot of the Blue Ridge on the northwestern or Valley side at an elevation of about 1,100 feet above sea-level, and just north of where Roanoke River breaks through the mountains.

East of the area the country is roughly mountainous, rising in places to an elevation of more than 2,500 feet, and is cut by many small streams which drain southward into the river, but toward the west there stretches a broad valley formed by the river and several large creeks that flow into it. Map, fig. 19, gives a good general idea of the topography of the area.

HISTORY AND DEVELOPMENTS.

According to Mr. Horace M. Engle,[a] of Roanoke, Virginia, the occurrence of ilmenite-apatite bodies (nelsonite) in the Roanoke County area was probably first noted by local parties about 1890. Some shallow openings were reported made and some of the ilmenite-rich ore was submitted to one of the Roanoke iron furnaces, but was rejected because of its low iron content and high phosphorus. Later, additional prospecting was done on several farms within the area under the direction of Mr. Engle, who has devoted some time to the investigation of the material. When visited and examined by the writers very little information of value could be obtained, since the shallow openings were of some years standing and had badly caved. Sufficient development work has not been done on which to base a definite statement as to the extent, especially depth, of the ore-bodies. Like the Nelson County ilmenite nelsonite bodies, those of the Roanoke County area show rather wide variation in the proportion of the two principal ore minerals, ilmenite and apatite.

GEOLOGY AND PETROGRAPHY.

GENERAL STATEMENT.

The ilmenite-apatite deposits lie wholly within the crystalline rocks of the Blue Ridge, and at a distance of about 1.5 miles from their contact with the Shenandoah limestone of Cambro-Ordovician age, which is traced through Vinton in a northeast-southwest direction.

The rocks of the area are in an advanced stage of decay from weathering, and exposures are rare. The development work accomplished does not penetrate below the depth of rock decay. These conditions make it impossible to accurately map the various rock formations, but the data obtainable are sufficiently definite to permit of drawing general conclusions as to their probable mode of occurrence and genesis.

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[a] Personal communication Aug. 19, 1912.

The rocks in the immediate vicinity of the ilmenite-apatite deposits are holocrystalline even-granular to porphyritic in texture, ranging from moderately coarse-grained in the syenite and pegmatite to very fine-grained in some of the nelsonites. They are igneous in origin, are intensely metamorphosed, and are divisible into a number of types which show a close genetic relationship like those composing the Amherst-Nelson counties rutile area. While the processes of rock differentiation and intrusion appear to have been similar in the two areas, the original magmas were probably different in composition, for they have given rise to rocks that aside from their ilmenite and apatite contents, show important differences in mineral composition. In both areas the rocks show the effects of intense metamorphism in the development of a foliated or gneissic structure, but notable differences are observed in the development of unlike secondary minerals. In the Amherst-Nelson counties area hornblende is of general occurrence as a secondary mineral, while in the Roanoke County area though some secondary hornblende is present, epidote is extensively developed in many of the rocks.

PRINCIPAL ROCK GROUPS.

Named in the probable order of their differentiation the principal rock types of the Roanoke area are: (1) Hypersthene-quartz syenite closely similar to akerite, (2) pegmatite partly altered to a rock of unakite composition, (3) nelsonite, and (4) diabase. These are described below in the order named. The rock types (2) and (3) may in places have been approximately contemporaneous in formation, but this is inconclusive, since the geologic relations were largely obscured by the depth of rock decay and the scarcity of exposures.

Hypersthene-Quartz Syenite

General character.—Of the four principal rock types identified in the Roanoke County area hypersthene-quartz syenite is the most extensive. It forms the country rock surrounding the ilmenite-apatite bodies and is cut by all the other intrusives. It is a medium greenish-gray rock of coarse-grained texture ranging from even-granular to porphyritic, the former (granitoid texture) predominating, and is usually gneissic in structure.

In the several specimens showing porphyritic texture orthoclase is the porphyritically developed mineral, the phenocrysts averaging about 3 cm. in length and twinned on the Carlsbad law. Schistosity was not apparent in all the hand specimens. Megascopically orthoclase and plagioclase feldspars, pyroxene, and some quartz were identified. Biotite is usually present in small flakes and garnet is often abundant. Graphite and ilmenite were observed in several hand specimens.

Microscopic character.—Under the microscope the rock is found in all cases to contain potash feldspar (orthoclase and microcline) and soda-lime feldspar (near andesine), pyroxene (hypersthene), quartz, and ilmenite or magnetite. Other minerals which are present in most but not in all thin sections are biotite, apatite, and titanite, together with the secondary minerals hornblende, kaolin, and ferrite (iron oxide stain).

Feldspar is the most abundant constituent and is composed of dominant orthoclase sometimes intergrown with a second feldspar probably albite as microperthite, usually a little microcline, and much plagioclase whose extinction angles correspond closely to andesine-oligoclase in composition. The feldspars exhibit both poikilitic and granophyric textures, and are twinned on the albite and occasionally the Carlsbad laws. Zonal structure was not observed. Granophyric texture is developed both in orthoclase and plagioclase intergrown with quartz. The feldspar shows some alteration to minute scales of kaolin more or less discolored from iron oxide.

Pyroxene, the next constituent of importance, varies in amount for the thin sections studied. It is the orthorhombic variety hypersthene and occurs usually in irregular plates of prismatic habit, exhibiting the usual pleochroism and cleavage, and is partly altered to fibrous pale green hornblende. Biotite, usually present in the hand specimens, is not shown in every thin section. It is developed in small shreds of brown color, strongly pleochroic, and exhibits the usual perfect basal cleavage.

Quartz in all the thin sections studied is developed in varying amount as formless grains of variant size. It usually exhibits slight optical disturbance from strain effects but granulation is seldom noticeable.

Ilmenite or magnetite is always present but in greatly varying amounts. It is generally developed in smaller masses than the principal constituents already mentioned. Apatite occurs both as inclusions in the other minerals and occasionally as separate larger individuals. Sporadic crystals of titanite and pyrite were identified in several thin sections.

Garnet, so generally present and frequently in considerable quantity in hand specimens, was not identified microscopically.

Comparison with syenite of the northern Blue Ridge, Virginia.—The hypersthene-quartz syenite of the Roanoke County area is almost identical with the coarse-grained dark gray syenite found on the west side of the Blue Ridge in Greene, Madison, and Warren counties, Virginia.[a] The rock ranges from massive to schistose in structure and is highly garnetiferous in places. In hand specimens the rock from the two localities is indistinguishable; in thin sections they are identical except that monoclinic pyroxene (diallage) is developed with hypersthene in the syenite area of the northern Blue Ridge.

According to Phalen[b] the unakite-bearing rock at Milam's Gap, Madison County, Virginia, is a hypersthene akerite (hypersthene-quartz-diallage syenite), a coarse-grained dark grayish-green aggregate consisting essentially of feldspars and black pyroxene. Thin sections of the syenite show the following minerals: Orthoclase, plagioclase, orthorhombic and monoclinic pyroxene, quartz, microcline, iron ore, apatite, and zircon, with the alteration products epidote, chlorite, and sericite. Hornblende is essentially absent in the thin sections.

An analysis of the syenite from the Roanoke County area was not made, but since the rock is essentially identical with that from the northern Blue Ridge area, the analysis made by Phalen on specimens of the syenite from Milam's Gap is given below to indicate the general composition of the Roanoke County rock.

Analysis of hypersthene akerite (hypersthene-quartz-diallage syenite) from Milam's Gap, Virginia.

(W. C. Phalen, *Analyst.*)

	Per cent.
SiO_2[a]	60.52
Al_2O_3	16.99
Fe_2O_3	0.60
FeO	6.53
MgO	1.59
CaO	4.58
Na_2O	2.83
K_2O	3.91
H_2O	0.88
P_2O_5	0.74
MnO	0.25
Cr_2O_3	Trace
ZrO_2	Trace
Total	99.42

[a] Including TiO_2.

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[a] Watson, Thomas L., Mineral Resources of Virginia, 1907, p. 32.

[b] Phalen, W. C., A New Occurrence of Unakite, Smithsonian Misc. Coll., 1904, vol. 45, pp. 306-316.

In the "Quantitative System" this rock falls into class II (dosalane), order 4 (quardofelic), rang 3 (alkalicalcic), and subrang 3 (sodipotassic). It is designated by the subrang name *harzose,* and its position may be expressed as follows:

Symbol	Name
II. 4. 3. 3.	Harzose

Pegmatite Partly of Unakite Composition.

While well-defined pegmatite dikes traceable at the surface were not observed, due very likely to the extensive surface decay of the rocks, several specimens collected from different localities within the area, strongly suggest their pegmatitic derivation. The general character of these is best indicated by separate detailed descriptions which follow below.

Specimen 232 was taken from a prospect pit in the bluff below the county road about 1.5 miles west of Vinton. It is a coarsely crystalline rock composed essentially of bright green epidote, pink orthoclase feldspar, and clear white quartz, with a few scattered grains of pyrite. The specimen is considerably weathered and the feldspars are partly kaolinized. The rock was probably derived from a pegmatite through epidotization of the feldspar, for though greatly altered it still shows hexagonal prisms of quartz, and intergrowths of quartz and feldspar. The average size of the individual minerals is about 0.5 cm.

Under the microscope a thin section of the rock showed the principal minerals yellow-green epidote, quartz, and some orthoclase together with the lesser minerals biotite (?), apatite, titanite, the alteration product leucoxene, and microscopic inclusions of rutile. The general character of the epidote indicates that it is of secondary origin. It is developed in small granules and larger platy forms of prismatic habit, and is noticeably pleochroic. Titanite shows its usual characteristic crystal form in cross sections. Quartz exhibits strain shadows, shows some granulation, and contains microscopic crystals of dark red rutile. Biotite is present in small amount and is considerably altered. Apatite is developed chiefly in large elongated forms.

Specimen 241 was broken from a piece of float about half a mile northeast of the one last described (Spec. 232). It is a light blue quartz probably of pegmatitic origin, for it contains small stringers and lenses of intergrown kaolinized feldspar. Microscopically a thin section of the rock showed it to be composed essentially of quartz intergrown with stringers of feldspar altered to minute scales of kaolin. The quartz exhibits pronounced wavy extinction and contains abundant inclusions, the principal ones of which are irregular, minute, dark dustlike particles, a few rutile needles and crystals, and a greenish mineral of larger size and altered, the exact nature of which was doubtful.

Nelsonite.

General statement.—Nelsonite is developed in numerous dikelike bodies in hypersthene syenite within the small area studied. Accurate observations on the size and shape of the masses and of their geologic relations to the inclosing rock were rendered difficult on account of the residual rock decay, exposures of fresh rock not being observed. The many shallow prospect openings made on the nelsonite bodies about 8 years ago were largely filled at the time of the field examination in September, 1910, hence their geologic relations were largely obscured. Sufficient data were procured, however, to indicate that the nelsonites have close similarity in form and mode of occurrence to those of the Amherst-Nelson counties area described on pages 100-155.

Megascopic character.—The nelsonite of the Roanoke County area is very dark gray nearly black in color, fine-grained and porphyritic in texture, and usually foliated in structure. Apatite is the porphyritically developed mineral which occurs in phenocrysts, sometimes exhibiting good crystal form, and ranging up to 4 or 5 cm. in diameter. The rock usually shows alteration from weathering, and some surface specimens exhibit the characteristic pitting from the removal of apatite by solution.

The general direction of strike of some of the bodies, determined from float and prospect openings, was N. 60° to 70° E. By this means one of the nelsonite bodies was traced on the surface for a distance of more than a quarter of a mile, while most of them could be traced for only short distances. The greatest width observed was about 50 feet.

Mineralogically the rock belongs to the ilmenite-apatite variety of nelsonite, rutile not being observed either in hand specimens or in thin sections except as occasional inclusions in other minerals. Epidote, biotite, and chlorite are frequently present, the former sometimes in considerable quantity, while feldspar is less often observed. Other minerals not apparent in hand specimens are identified in thin sections under the microscope. The frequent presence of epidote, sometimes in large quantity in the nelsonite bodies of this area, is a characteristic feature not shown in those of the Amherst-Nelson counties area.

The nelsonite float in this locality varies much in appearance; some of it exhibits porphyritic texture and is composed entirely of apatite and ilmenite, while other pieces show large amounts of secondary epidote and chlorite. Much of the ilmenite is altered to limonite and some large pieces of nearly pure limonite were found. The ilmenite of this area apparently alters to limonite more readily than that of the Amherst-Nelson counties area, and it is usually more strongly magnetic.

Microscopic character.—The microscopical petrography of the nelsonite in the Roanoke County area is comparatively simple, and as stated above it belongs to the ilmenite-apatite variety of the rock. Every thin section examined revealed the presence of several silicate minerals in addition to the principal ore minerals, ilmenite and apatite. The list of silicate minerals is fairly large, but not all of them occur in any one of the thin sections and several are very sparingly developed. The proportion of ore minerals to silicate minerals is variable, with the former predominant. Likewise the ratio of the ore minerals, ilmenite and apatite, is variable, although for the thin sections studied ilmenite is usually in excess of apatite. Some specimens, however, show apatite to be in excess of ilmenite.

Microscopically the nelsonite is composed of ilmenite and apatite as the principal constituents, with a little unstriated feldspar, sometimes much biotite, occasional quartz, and in one thin section hornblende and less pyroxene. Much secondary epidote is developed the exact derivation of which is in doubt. It has probably been derived in part at least by the interaction of ferromagnesian minerals and feldspar, although its intimate association at times with apatite suggests that the alteration of this mineral has entered possibly in part into the formation of epidote. The alteration products of ilmenite and apatite, leucoxene and osteolite, are developed to a limited extent. Hydrous oxide of iron as a yellowish-brown stain is freely developed from the alteration of the iron-bearing minerals, chiefly ilmenite. Pyrite occurs but by no means so abundantly as in the nelsonites of the Amherst-Nelson counties area.

The relations of ilmenite and apatite to each other suggest their probable approximate contemporaneous formation. In some thin sections the two minerals exhibit the relations of intergrowths; in others ilmenite contains inclosures of apatite, and apatite sometimes carries inclusions of ilmenite. The stronger tendency of apatite to develop crystal outline suggests that, in some cases, it probably crystallized slightly in advance of ilmenite.

INDIVIDUAL DESCRIPTION.

On the Bush farm 1.5 miles east of Vinton several nelsonite dikes have been located. One of these is on the hill about 50 feet south of the county road. Much float was found extending for a distance of about 250 yards in a direction N. 60° E. Several prospect pits were sunk along the line of this dike but had filled prior to the field examination in September, 1910. Three specimens (229, 230, and 231) were selected from the freshest material obtainable. These three specimens are separately described below.

Specimen 229 is a porphyritic nelsonite exhibiting foliated structure. It consists of numerous phenocrysts of white apatite imbedded in a very fine-grained, bluish-gray ground-mass of chiefly ilmenite. The apatite crystals are for the most part drawn out into thin bands 1 cm. or more in length, 2 to 3 mm. wide, and only a fraction of 1 mm. in thickness. A greenish-brown secondary mineral probably epidote is present in irregular branching streaks. Microscopically the rock is composed of ilmenite, apatite, unstriated feldspar probably orthoclase, and titanite, together with secondary epidote, leucoxene, and iron oxide staining. Ilmenite and apatite show the same relations as described below under specimen 231. The feldspar exhibits wavy extinction and slight granulation, and contains inclusions of probable ilmenite.

Specimen 230 is a porphyritic nelsonite. The apatite phenocrysts are prismatic in habit, sometimes exhibiting good crystal form, and range up to 3 mm. in width and 1 cm. in length. They are imbedded in a groundmass of bluish-black ilmenite inclosing numerous small grains of apatite which show occasional hexagonal cross-sections. The large apatite crystals are partly decomposed and removed by solution, but a few of the smaller ones are fairly fresh. A little altered biotite is present. Where long exposed to weathering the rock surface becomes dark brown from the production of limonite and deeply pitted by the removal of apatite. Under the microscope a thin section of the rock shows the principal minerals to be ilmenite and apatite chiefly, much biotite, some titanite, and a few grains of unstriated feldspar, together with much epidote associated usually with the apatite, some leucoxene, osteolite, and iron oxide as stain. Ilmenite contains inclosures of apatite, and apatite carries inclusions of ilmenite some of which exhibit crystal boundaries. The biotite folia are considerably bent, show strong absorption and good cleavage, and are partly altered to chlorite and epidote. The thin section is greatly altered.

Specimen 231 is similar to 229, but has undergone more alteration, the ilmenite having changed largely to limonite. Microscopically a thin section shows ilmenite and apatite to be the principal minerals with much secondary epidote and a little leucoxene. Ilmenite and apatite show the same relations as described above under specimen 230. Along the margin of a part of the apatite and extending towards the center of individuals, the two minerals strongly exhibit the relations of intergrowths, but more often the apatite is crowded with skeletal ilmenite inclusions.

About a quarter of a mile southeast of the nelsonite bodies described above occur two or more dikes on which some prospecting has been done. The larger of these could be traced for more than a quarter of a mile in a direction N. 65° E., and in one of the surface cross-cuts it was exposed for a maximum width of about 50 feet. It is a gray rock containing apatite as the dominant mineral in grains ranging up to 2 mm. in diameter, with some chlorite and very little ilmenite. A smaller dike (Spec. 245) that appears to nearly parallel the larger one is a fine-grained, dark bluish-gray nelsonite. A thin section of this rock under the microscope shows it to be very fine-grained in texture, and composed essentially of ilmenite and apatite, a little biotite, and a sprinkling of quartz. The relations of the apatite, ilmenite, and quartz, suggest nearly simultaneous crystallization, the evidence for this consisting chiefly of mutual inclosure and penetration of the three minerals. Apatite shows some alteration and contains dust-like inclusions of probable ilmenite. Quartz carries inclusions of rutile in grains and crystals and exhibits some optical disturbance from the effects of dynamic forces. The few shreds of light brown biotite display the usual pleochroism and cleavage. Several crystals of titanite were noted, and a sprinkling of deep red crystals of squarish outline occur which suggest secondary rutile. The thin section is freely discolored from iron oxide staining. (See Pl. XXXV, fig. 1.)

About 100 feet north of the dikes first described (Spec. 229 to 231) is another (Spec. 233) that is similar and approximately parallel, exposed along the steep slope below the north side of the road. A number of prospect pits and ditches have been opened along the course of the dike and there are several large outcrops indicating a maximum width of about 30 feet. A specimen of the rock taken from this dike (Spec. 233) is composed of apatite in grains about 1 mm. in diameter, some of which show hexagonal cross-sections, with hornblende, epidote, and ilmenite filling the interstices. Epidote also occurs in more or less lenticular masses 3 to 4 cm. in length, and a small amount of pyrite is present. Under the microscope thin sections of this rock show it to be composed of apatite, ilmenite, hornblende, a few pieces of pyroxene, an occasional grain of

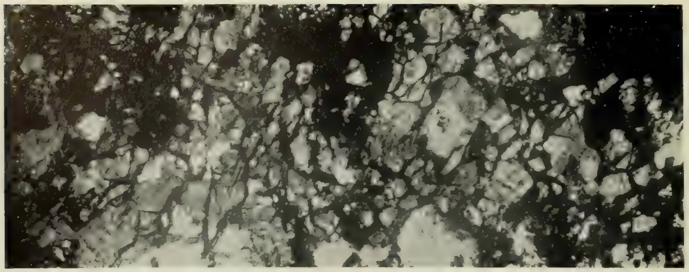

Fig. 1.—Fine-grained ilmenite nelsonite. Light areas apatite, dark areas ilmenite. Single nicol. Enlarged 30 diameters. Specimen No. 245.

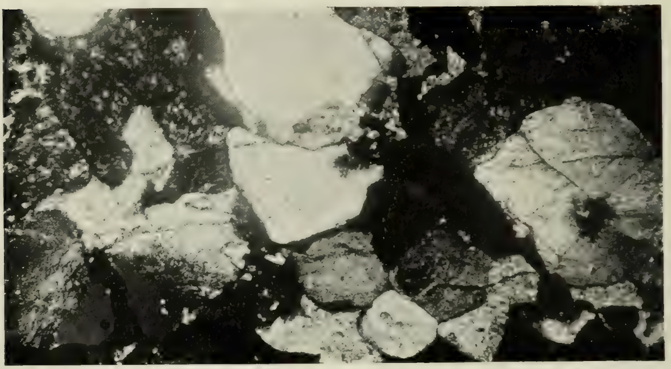

Fig. 2.—Epidote-bearing ilmenite nelsonite, showing apatite (light nearly white areas), ilmenite (black areas), and epidote (medium dark areas). Nicols crossed. Enlarged 30 diameters. Specimen No. 233.

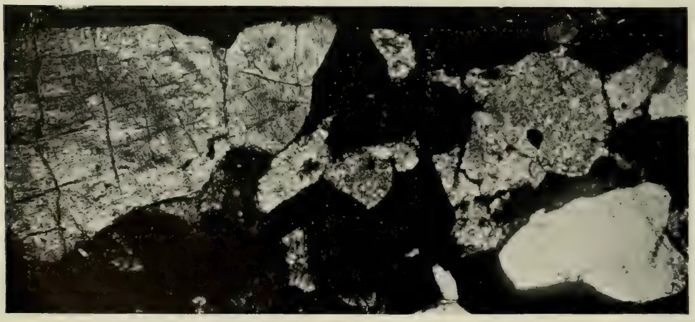

Fig. 3.—Epidote-bearing ilmenite nelsonite. Same as fig. 2. Nicols crossed. Enlarged 30 diameters. Specimen No. 233-B.

PHOTOMICROGRAPHS OF ILMENITE NELSONITE FROM ROANOKE COUNTY.

titanite, together with much secondary epidote and some leucoxene. The two thin sections are greatly altered and stained from the presence of much free hydrous oxide of iron derived in part from the oxidation of pyrite. Several shreds of light-colored mica were identified. Apatite shows a noticeable tendency toward hexagonal outline and was probably the first mineral to crystallize from the magma. Hornblende is developed in irregular platy forms, a part of which is bluish-green and pleochroic, frequently displaying both cleavages; the remainder is the bluish "reedy" form and is certainly secondary. It is entirely probable that none of the hornblende is original or primary. Pyroxene is less abundant than hornblende from which it can be distinguished only by parallel extinction because of discoloration from the development of iron oxide. Epidote of pronounced pleochroism is abundantly developed in grains and platy forms, the latter often exhibiting good cleavage. This mineral is secondary and, as a rule, occupies distinct areas but it is frequently closely associated with the hornblende. Plate XXXV, figs. 2 and 3, shows microphotographs of the two thin sections of this rock.

About a quarter of a mile northeast of the nelsonite dike last described (Spec. 233) is another (Spec. 243) the strike of which, as exposed by a number of surface openings, is approximately N. 67° E., and the length not less than 200 yards. The rock is composed of white apatite ranging from grains almost microscopic in size up to those (phenocrysts) 4 or 5 cm. in diameter, bluish-black ilmenite, and a little chlorite or altered biotite. Some of the apatite shows roughly hexagonal outline. Studied in thin section under the microscope the principal minerals are ilmenite and apatite, with some biotite and secondary epidote, a single grain of quartz, and much free hydrous oxide of iron as stain. Ilmenite and apatite show the usual relations, that is, the latter exhibits a marked tendency toward crystal outline, is partly inclosed by the ilmenite, and probably crystallized in advance of the ilmenite. The apatite is greatly altered.

On the Hutchins farm about 600 yards farther north much nelsonite float is found (Specs. 235 and 239), indicating the presence probably of a large dike, but no development work has been done and there are no outcrops. A stone wall in the vicinity is constructed largely of the nelsonite float. In a gully near this point an occurrence of nelsonite, in residual soil derived from the country rock (syenite), was observed which had the appearance of a segregation rather than of a true dike intrusion, but the weathering was too great to permit of drawing definite conclusions.

Diabase.

Only one diabase dike was observed within the limits of the area, and that was in an advanced stage of decay from weathering. The county road crosses the dike about 150 yards east of Mr. Hutchins' dwelling house. The dike was too much altered to obtain a hand specimen, but so far as could be determined it presented no unusual features.

GENESIS.

It will be readily observed from the detailed descriptions already given of the rock types forming the small area mapped, that the rocks are igneous in origin, and show close genetic relationships in mineral composition. The writers consider them to be differentiation products of a common magma, formed in the probable order given on page 237.

The relationship of the syenite and nelsonite is shown (1) by their close association, and (2) by the presence of similar minerals in each. The two rocks differ from each other mineralogically more in the proportion than in the kind of minerals composing them. In general the principal minerals in one type make up the minor accessory minerals in the other. Feldspar, pyroxene, quartz, and biotite, are the principal silicate minerals in the syenite, and each of these has been developed, though unequally, several very sparingly, in the nelsonite. Likewise the dominant minerals, ilmenite and apatite, of the nelsonites occur as microscopic accessory minerals in the syenite. No account is taken here of the secondary silicate minerals, epidote, chlorite, and hornblende.

Unfortunately the exact nature of the contacts formed by the syenite and nelsonite could not be determined, since they were obscured by the profound rock decay which mantles the entire area. It could not be ascertained therefore whether the boundaries between the two rocks were usually sharp and well defined or whether they were largely gradational. This is important since it would greatly aid in determining whether the nelsonite bodies were intruded into the syenite after that rock had completely solidified, or whether they were formed earlier and are to be regarded as more closely akin to magmatic segregations than to true igneous intrusions.

From the general mode of occurrence of these masses in the syenite and their close similarity to those of the Amherst-Nelson counties area they are regarded by the writers as magmatic basic segregations somewhat similar in mode of origin to the well-known segregations of titaniferous magnetite in gabbros. They represent differentiations from the magma which gave rise upon cooling to the syenite and other igneous rock types in the area, and in point of time their formation was probably approximately contemporaneous with that of the inclosing syenite.

AGE.

There are no conclusive data at hand on which to base a definite statement as to the exact age relations of the rocks forming the small area mapped. The rocks are all igneous in origin, are in general intensely metamorphosed, and the area forms a part of the Blue Ridge proper. The eastern edge of the Cambro-Ordovician sediments is removed only a short distance west of the area and farther down slope. Bearing these facts in mind and our present knowledge of the Blue Ridge in general, the area may be assigned provisionally to the pre-Cambrian. Whether the single dike of diabase observed in the area should be included, or assigned to a later period of time, is doubtful, since its extreme alteration from weathering rendered its exact nature difficult and uncertain.

GEOLOGY OF THE ORE-DEPOSITS OF GOOCHLAND AND HANOVER COUNTIES.

LOCATION OF RUTILE DEPOSITS.

The recently discovered rutile deposits near the central-eastern margin of the Piedmont province in Virginia, are located in the northeastern corner of Goochland County and in the adjacent extreme southwestern part of Hanover County. They are further located on the Bowe and Brown farms near Gouldin and Waldelock, Hanover County, 25 miles northwest of Richmond, and on the Nuckols farm between Peers and Johnson's Springs, Goochland County, 17 miles west of Richmond (see map, fig. 20).

The Hanover County deposits lie about halfway between the main line of the Chesapeake and Ohio railway on the north and the James River division of the same railway on the south. They are about 12 miles nearly due south from Beaver Dam station on the main line, and about the same distance northeast from Maidens, a station on the James River division of the Chesapeake and Ohio railway. The nearest railway station to the Goochland County deposits, distant 6 to 8 miles south of those in Hanover County, is Sabot, on the James River division, about 6 miles south 15°-20° west.

HISTORY.

The discovery of rutile in Goochland and Hanover counties, Virginia, was announced in 1910. Loose rutile ranging in size from very small grains to masses weighing more than 20 pounds, associated with ilmenite, which litter the surface in the localities named above and derived by weathering from a certain type of underlying rock (pegmatite), led to the identification of the mineral. At one place on the Nuckols farm near Peers, in Goochland County, the remnants of former prospect openings are still visible. These are reported to have been made more than 100 years ago in search for ruby silver, and it has been suggested that the prospectors probably mistook the red rutile for silver ore.

The localities were visited by Frank L. Hess, of the U. S. Geological Survey in May, 1910, who was the first geologist to describe them.[a] They were subsequently visited and studied by the writers in December, 1910.

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[a] Hess, Frank L., New Rutile Deposits near Richmond, Va., Mng. World, 1910, xxxiii, pp. 305-307.

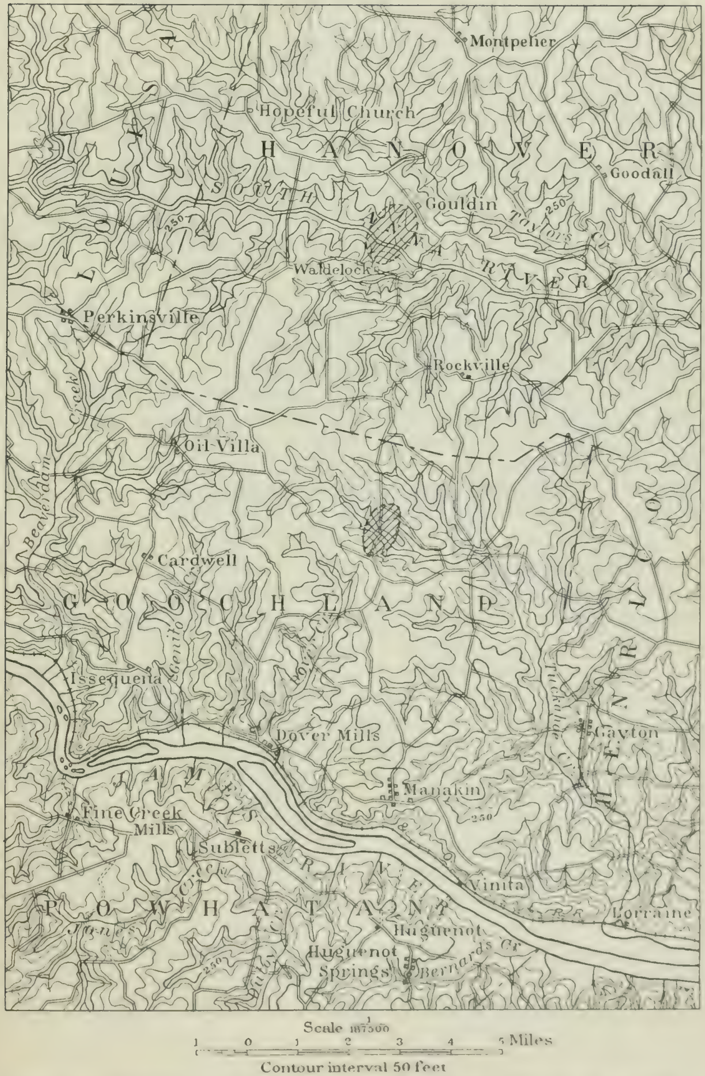

Fig. 20.—Topographic map of a part of Goochland and Hanover counties, Virginia, showing location of rutile areas. (Based on the Goochland sheet of the U. S. Geol. Survey.)

TOPOGRAPHY.

Map, figure 20, adopted from the Goochland sheet of the U. S. Geological Survey and covering parts of Goochland and Hanover counties, gives a good general idea of the topography of the eastern Piedmont border region in which the rutile deposits near Peers, Waldelock, and Gouldin, occur. The area comprised within the limits of the map averages about 300 feet above sea-level and is drained by South Anna and James rivers, and their tributaries. It is a part of a moderately dissected plateau surface, without marked elevations found over any of its parts. The range in elevations is from less than 150 feet in the James River basin and about 200 feet in the South Anna valley, to more than 350 feet over parts of the divide region between the two drainage systems.

The rutile area at Peers in Goochland County lies in the upper drainage basin of Tuckahoe Creek, a tributary to James River, while the deposits near Waldelock and Gouldin in Hanover County lie close to South Anna River, on the south and north sides of the river, respectively.

GENERAL GEOLOGY AND PETROGRAPHY.

INTRODUCTORY STATEMENT.

In common with the Piedmont province in general, the rocks of this eastern border region in which occur the rutile deposits of Goochland and Hanover counties, are in an advanced stage of decay, and the hard moderately fresh rocks are concealed beneath the cover of variable thickness derived by the normal processes of weathering. Exposures in the region, therefore, of even moderately fresh rock are rare except along and in the vicinity of stream courses. Because of this fact and in the absence of sufficient development work (openings), the exact detailed geologic relations are difficult of complete and accurate interpretation. However, we believe that our studies in the region have been sufficiently detailed to definitely state the principal facts relating to the geology.

As regards rock (types) associations, the rutile occurrence in Goochland and Hanover counties is unlike that of the Amherst-Nelson counties area, but the two areas are similar in that rutile is associated with ilmenite, and in each area the accompanying rocks are igneous in origin. Nelsonite, an important rock type in the Amherst-Nelson counties and the Roanoke County areas, is not known to occur in Goochland and Hanover counties. Indeed there is an almost entire absence of apatite from the several rutile localities in the latter counties.

PRINCIPAL ROCK GROUPS.

Where observed the rock exposures show the country rock to be a granitic gneiss of variable composition, chiefly micaceous (biotite and muscovite) and at times hornblendic, cut in many places by numerous dikes of acid (granitic) pegmatite some of which are rutile-bearing, and a variety of basic igneous rocks, including diorite, diabase, and pyroxenite. These are described below in the order named.

Gneiss.

The country rock of the region is a gneiss of variable composition, and contains much biotite and hornblende, with the usual large quantities of feldspar and quartz, the proportion of which varies from place to place. The gneiss bands containing biotite as the principal dark mineral alternate in some localities at least with those containing hornblende. This is well shown in a fresh section of the gneiss (garnetiferous) exposed in the railroad cut just east of Sabot. In other places the gneissic bands are composed almost exclusively of white feldspar, with usually some colorless mica, and a little quartz. The highly feldspathic gneiss is extensively developed in the several rutile areas extending from the Bowe farm in Hanover County, southward 8 miles to the Nuckols farm in Goochland County, and probably farther. A thin section cut from feldspar collected from the more feldspathic phase of the gneiss on the Brown farm at Waldelock shows it to be perthitic orthoclase, having good cleavage and free from inclusions.

The rock varies from medium- to moderately coarse-granular in texture, and from light nearly white to dark in color, according to whether the dark minerals, biotite and hornblende, are present and their quantity. They exhibit pronounced foliation or banding. While a chemical analysis of the rock has not been made, thin sections of the gneiss studied under the microscope conform in composition to an original acid igneous rock, corresponding to a granitic type more closely allied to quartz monzonite, and the banded structure to be secondary induced by regional dynamic forces.

Microscopically the essential minerals are feldspar (orthoclase with variant microcline and much plagioclase near oligoclase) and quartz, with which are associated in different bands of the rock biotite or hornblende, and in the feldspathic portions muscovite, together with garnet, titanite, and apatite.

The gneiss is cut by numerous pegmatite dikes which usually lie in the foliation planes, and some of which are rutile-bearing. It is also cut by dikes of basic igneous rocks of the several types described below.

Pegmatite.

Pegmatite dikes, ranging from several inches to 4 feet and more in width, of light color and granitic composition, cut the gneiss rather abundantly in places. They lie mostly in the structure planes of the gneiss and like the inclosing rock have been mashed and rendered schistose by pressure effects. Much of the feldspar has been granulated and the quartz is frequently mashed into lense- or stringer-like masses. Likewise the larger masses of rutile show granulation similar to the feldspar. The pegmatite bodies cutting the gneiss exposed in the railroad cut east of Sabot are coarse-granular and massive, and the feldspar is chiefly of pink or flesh color. Rutile was not observed in any of them.

Like the inclosing gneiss the pegmatites are invariably decomposed for a considerable depth below the surface. In many cases the feldspars have reached an advanced stage of kaolinization, which frequently renders the identification of the species almost or entirely impossible. In some of the freshest specimens, however, twinning striæ were plainly visible on cleavage surfaces of a part of the feldspar (plagioclase), while other grains could be as definitely identified as a potash variety, orthoclase or microcline, chiefly orthoclase.

The pegmatites are highly feldspathic, containing both potash and soda-lime varieties with some quartz, partly of the dark smoky variety, less muscovite and biotite, and in some rutile associated with ilmenite (Pl. XXXVI, fig. 1). The rutile is an original constituent of the dikes and occurs in grains and masses up to many pounds in weight (fig. 21). The rutile-bearing dikes, exposed by prospecting on the Bowe and Nuckols farms, are described on pages 258-260.

Microscopic study of thin sections of the pegmatites serves only to confirm the mineral composition and textures described above. Both potassic and sodic feldspars (orthoclase and plagioclase) occur, the former greatly in excess in some, and the two in nearly equal proportions in others. Sericitization and kaolinization of the feldspars are pronounced. In addition to the foliated structure shown in hand specimens mashing of the feldspars and quartz is emphasized in thin sections under the microscope.

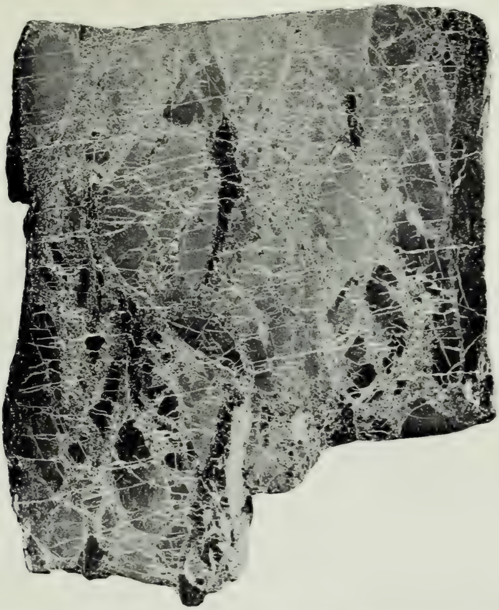

Fig. 1.—Polished section of a piece of rutile float on the Bowe farm near Goulden, Hanover County. Shows fine brown-red rutile with intergrown ilmenite. The pegmatite dike from which the rutile weathered has been mashed until the rutile is squeezed into oval-shaped and lenticular masses between which are fine granular particles of the same mineral; and the whole subsequently fractured with joints running in two directions. (Collected by Frank L. Hess. Photographed by U. S. Geol. Survey.) Natural size.

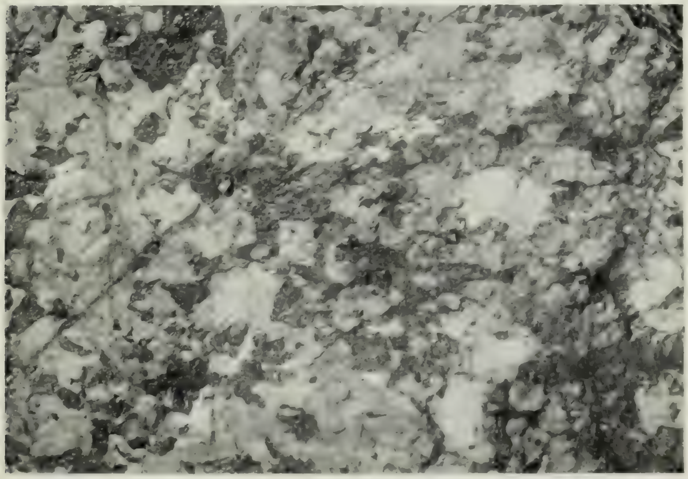

Fig. 2.—Section of specimen showing intergrown quartz and rutile. Light-colored areas quartz, dark areas rutile. Natural size.

RUTILE ORE AND INTERGROWTHS OF RUTILE AND QUARTZ.

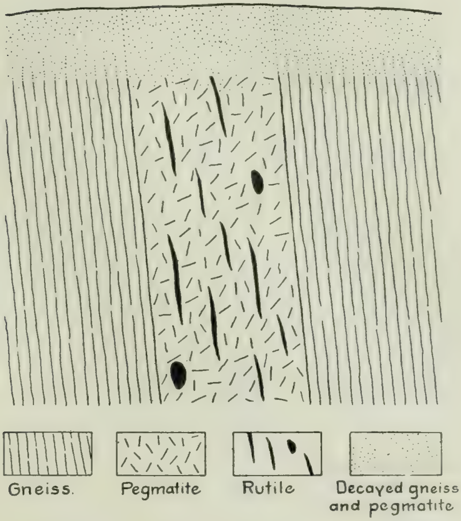

Fig. 21.—Sketch of pegmatite dike in Goochland County, Virginia, showing its relations to the inclosing granite-gneiss and mode of occurrence of rutile.

Diorite.

Diorite is found at a number of localities in the district, but the exposures are poor, and the geologic relations difficult of interpretation, because of the depth of residual rock decay. Exposures of the rock that afforded reasonably good specimens were noted on the road between Maidens station and the Bowe farm (Spec. 248), on the Brown farm at Waldelock (Spec. 257), and on the Bowe farm 500 yards north of South Anna River (Spec. 253).

Hand specimens of the rock from the several localities mentioned above show diorite of dark greenish-gray to greenish-black color, and ranging from fine to coarse even-granular in texture. They are essentially massive although several specimens exhibit faint schistose structure. Black, cleavable, hornblende in grains and prismatic crystals ranging up to 5 by 8 mm. in size, is the dominant mineral, with feldspar, a little quartz, and tarnished sulphides (pyrite chiefly) visible, megascopically. The hornblende individuals average larger in size than those of feldspar. Twinning striæ are observed on much of the freshest feldspar. Much of the feldspar, however, is more or less altered and chalky in appearance. Epidote is readily visible with the aid of the pocket lens.

Thin sections of the rocks show no unusual features when examined under the microscope. They are composed of fine- to coarse-granular mixtures of hornblende (chiefly) and plagioclase feldspar. with accessory quartz, orthoclase, titanite, and apatite, together with secondary epidote, colorless mica, and iron oxide. Hornblende of brown to green and blue-green color occurs mostly in irregular platy forms, less often in euhedral crystals, and usually exhibits good cleavage and strong absorption. Inclosures of quartz and feldspar having rounded outlines are noted in some of the larger hornblende individuals. Lime-soda feldspar (plagioclase) is the next most abundant mineral. It is quite fresh in some thin sections but in others its substance is largely obscured by alteration products. Limonite pseudomorphs after pyrite are noted in thin section 253. Quartz is subject to wide variation in amount, being developed but sparingly in some thin sections and fairly plentiful in others. It is partly secondary in some cases.

Diabase.

Only one occurrence of diabase was noted by the writers in the rutile areas of Goochland and Hanover counties. This was observed on the Bowe farm a short distance north of South Anna River. It is a normal Mesozoic diabase of fine-grained texture and blue-gray color. Under the microscope a thin section of the rock (Spec. 254) shows typical diabasic texture and is composed of plagioclase feldspar (labradorite), augite. and magnetite. These present no unusual characters for a diabase.

Pyroxenite.

Pyroxenic masses (Specs. 250, 251, 255, and 260) probably dikes, are found on the Bowe farm (Specs. 250 and 251), Hanover County, and on the Brown (Spec. 255) and Nuckols (Spec. 260) farms, Goochland County. The occurrences noted on the Bowe farm are exposed in some of the openings made in prospecting for rutile.

The pyroxenites are medium- to coarse-granular, massive, dark rocks, exhibiting distinct bronzy luster. more or less altered from weathering, and discolored from iron oxide. In addition to pyroxene, ranging up to more than an inch across, accessory quartz probably secondary in most cases, pyrite and pyrrhotite, and ilmenite or magnetite (Spec. 260) occur. Specimen 251 exhibits several areas, measuring more than an inch in diameter, composed of quartz mostly of blue color and rounded outline.

Thin sections show the rocks to be composed chiefly of nearly colorless non-pleochroic pyroxene, having good cleavage development, and frequently crowded opaque brown inclusions arranged in definite positions. These are developed as plates, rods, and grains oriented in part parallel to the cleavage, and in part at angles to this direction. Some of the inclusions were identified as rutile, but most of them were indeterminate.

The accessory minerals include ilmenite or magnetite, biotite which is partly secondary, chlorite, and in thin section 250 some colorless garnet filled with inclusions and associated with a little secondary quartz. The sulphides, pyrite and probably some pyrrhotite, were identified in hand specimens of the rock, but were not observed in thin sections.

The Rutile Ore.

GENERAL CHARACTER.

Megascopic character.—Megascopically the rutile occurring at the several localities in Goochland and Hanover counties is similar in general physical character to the syenite rutile of Nelson County described on pages 193-196, except that many of the larger pieces are massive fine-granular composed of an apparent aggregate of small grains measuring 0.2-8± mm. in diameter, which is probably due to mashing from dynamic forces. It is usually deep red in color, sometimes brownish-red, has the characteristic metallic-adamantine lustre, and while no chemical analyses have been made of the mineral, it has every physical appearance of being very pure. It ranges in size from small grains up to masses weighing 15 or 20 pounds and occasionally more. Several masses of the pure mineral were observed on the surface at one of the shafts on the Nuckols farm which exceeded 20 pounds each in weight. Hess mentions one mass found on this farm that was reported to have weighed 200 or 300 pounds.

Microscopic character.—Microscopically thin sections of the rutile (Specs. 249, 261, and 262) exhibit no unusual characters. Each thin section agreed in showing a granular aggregate of the mineral, which was light yellow-brown, sometimes deep golden yellow, by reflected light, and very faintly or non-pleochroic by transmitted light. The hand specimens are deep red in color and show a massive fine-granular structure. Good cleavage development is observed in some grains, and irregular fractures are common. No inclusions were identified and as a rule alteration is not shown, although occasional incipient alteration to leucoxene about the margins of some grains was indicated. In two of the thin sections (261 and 262) the rutile is intimately admixed with more or less black ilmenite which exhibits a tendency toward outward crystal form. In one of the thin sections (262) an occasional light-colored silicate mineral was observed.

Ilmenite.—The ilmenite found in the Goochland and Hanover counties areas has the same mode of occurrence as the rutile with which it is associated. It may occur as separate grains and masses or admixed and intergrown with the rutile as shown in Pl. XXXVI, fig. 1. An analysis of the ilmenite collected by Mr. Hess from the Goochland County area gave the following results:

Analysis of ilmenite from Goochland County, Virginia.

(R. C. WELLS, *Analyst.*)

	Per cent.	*Ratio.*
TiO_2	51.83	.648
FeO	46.22	.642
SiO_2	2.31	.038
	100.36	

As shown by the ratios of titanium and iron oxides calculated from the analysis, the Goochland County ilmenite corresponds closely to the formula $FeO.TiO_2$. This analysis is compared with analyses of the same mineral from the Amherst-Nelson counties area, and the composition of the latter discussed on pages 223-226.

MODE OF OCCURRENCE.

The rutile associated with ilmenite occurs (a) as loose grains and masses on the surface and in the soil derived by normal weathering processes from the underlying fresh rock, and (b) as dots and streaks in pegmatite dikes of granitic composition (fig. 21) which cut the gneiss. The pegmatite is described on page 252. Still a third mode of occurrence is in the highly feldspathic portions of the gneiss, as was observed in the rock exposures along the small stream on the Bowe farm. Here rutile and ilmenite occur in very thin streaks or stringers which probably represent crushing of larger grains of the two minerals by the forces of metamorphism.

MINERAL ASSOCIATIONS.

Apart from the usual silicate constituents of the pegmatites—feldspar, quartz, and mica (muscovite and biotite)—the minerals associated with the rutile are exceptionally few. Ilmenite is much the most frequent one and may occur as separate grains and masses or as an intimate mixture or intergrowth with rutile (Pl. XXXVI, fig. 1). Occasional apatite has been observed with the rutile and ilmenite. Besides ilmenite and occasional apatite there is indication in places of the former presence of pyrite in hydrous iron oxide which was apparently formed from the decomposition of the original sulphide mineral.

GENESIS.

The abundant grains and larger masses of rutile found loose on the surface and in the soil have been derived from the underlying rock (pegmatites chiefly, and in places possibly to a limited extent from the more feldspathic portions of the inclosing gneiss) by the usual processes of weathering.

The area in which the several occurrences of rutile are noted is one of igneous rocks that have been profoundly changed by metamorphism, except the dikes of basic materials, some of which are probably of later age. Both the inclosing rock (granite-gneiss) and the pegmatites have shared alike in the periods of deformation and are now strongly schistose in structure. That the rutile was formed prior to the metamorphism affecting the rock in which it occurs is evidenced by its showing pressure effects in crushing and mashing. Both the rutile and ilmenite frequently occur in thin stringers oriented in the direction of schistosity, formed probably by the crushing of larger particles of the two minerals.

As has been previously stated the rutile is associated with ilmenite, and has unequal distribution in the pegmatite dikes. For the depth reached in prospecting, rutile has nowhere been found in the dikes in as large masses as those composing the float and from which it must have been derived. Probably larger bodies of rutile will be found in the dikes at greater depth, but at what depth can not be stated. No explanation can be offered for the unequal distribution of the rutile in the dikes, except on the basis of a process similar to that which resulted in the formation of the principal silicate minerals, feldspar and quartz.

So far as field and laboratory studies indicate, both the rutile and ilmenite must be regarded as original constituents of the pegmatite dikes, formed by the same processes and practically at the same time as the principal silicates—feldspar, quartz, and mica. Since their formation, the dikes containing rutile have been subjected to intense dynamic metamorphism in common with the inclosing rock (granite-gneiss), which resulted in the development of pronounced schistosity in both. There is no evidence to indicate that the rutile bears any genetic relationship to the dikes of basic igneous rocks in the several localities.

The more highly feldspathic portions of the gneiss containing rutile, as described above, may possibly represent pegmatitization.

AGE OF THE DEPOSITS.

Reference to the geologic map of Virginia[a] will show that the several rutile occurrences described above are located near to the northern end of the Triassic area known as the Richmond Coal basin. The rocks forming this basin, however, are unconformably deposited on the gneiss cut by the rutile-bearing pegmatites and are therefore later in age. Moreover, it has been shown that both the gneiss and pegmatite dikes are schistose, a structure developed in the rocks before Triassic time, and they can not be younger than Carboniferous, the last intense period of metamorphism which affected the rocks of the eastern United States. The rocks forming the area in which the rutile is found are considered to be of pre-Cambrian age, and if the genesis outlined above is correct, the rutile deposits are likewise pre-Cambrian.

ECONOMIC CONSIDERATIONS.

MINING DEVELOPMENTS.

Prospecting for rutile in these counties has been limited chiefly to the Bowe farm near Gouldin on the north side of South Anna River, Hanover County, and to the Nuckols farm, 8 miles farther south, near Peers in Goochland County.

Bowe farm.—On the Bowe farm abundant loose rutile grains and masses weighing 20 pounds and more are scattered over the surface of an area of more than 50 acres in extent. Within this area, a short distance to the southwest and southeast of the Bowe dwelling house, several shallow pits not exceeding 20 feet in depth were opened by August Meyer, who leased the property. The descriptions of the openings, published by Mr. Hess, shortly after his examination of them and when they were in better condition for study than at the time of the writers' investigations, are quoted in full:[b]

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[a] Watson, Thomas L., A Geological Map of Virginia. Va. Geol. Survey, 1911.

[b] Hess, Frank L., New Rutile Deposits near Richmond, Va., Mng. World, 1910, vol. xxxiii, p. 305 *et seq.*

"On a hill southwest of the Bowe farmhouse two holes were sunk 15 or 20 ft. deep; a pegmatite dike about 3 ft. wide has been cut in each . . . Both the enclosing gneiss and the pegmatite are so decomposed that insects and worms have burrowed through them as deeply as the prospect holes have gone. The dip of the dike is about 70° west, and it follows the strike of the rocks, north to south.

"For 10 or 12 ft. from the surface, the rocks are so discolored by iron as to be indistinguishable. Below that the decayed (kaolinized) pegmatite is white and chalky and is from 3 to 4 ft. wide. Through it are dots and streaks of reddish rutile ½ in. thick. Some of the rutile stringers are accompanied by quartz of similar thickness. There are streaks of biotite mica from 1 to 3 ins. wide, and 2 or 3 ft. long with which in several places are stringers of rutile and ilmenite from ½ to ¾ in. thick. The various narrow bands and stringers in the pegmatite may represent in part flow structure, but are also due to later crushing. The whole dike has been crushed until it has taken on something of the gneissoid appearance of the surrounding rocks. The quartz has been recemented and is comparatively solid, but the rutile is in angular fragments and has not been recemented. There is some hydrous iron oxide which appears to have been formed from the decomposition of pyrite. In the more southerly of the prospect holes, which are only 15 ft. apart, the rutile occurs in thin stringers throughout the width of the dike. The stringers are about ½ in. or less thick, and about 2 to 3 ins. apart.

"Among the float picked up along the hill are pieces of rutile which have evidently come from the gneiss alongside the dike, as they are so much more crushed than the dike itself. These pieces are lenticular and up to 4 or 5 ins. broad by 2 ins. thick. Some are made up of ilmenite with streaks of rutile. In other specimens the mass is made up of rutile with a thin envelope of ilmenite ⅛ in. thick. The iron and titanium in the ilmenite have practically the proportions that should be found in the theoretically purer mineral. (See analysis on page 256.) Some apatite occurs with the rutile and ilmenite.

"No rutile has been found in the prospect holes in as large bodies as those from which the float must have come. It is probable that if the prospect holes are continued downward larger bodies of rutile will be encountered, but at what depth or in how many places can not be prophesied.

"On a hill one-fourth of a mile southeast of the Bowe house, float rutile has also been found, but on this hill it is accompanied by much more ilmenite. In a prospect hole stringers similar to those upon the hill first described were cut, but as the float indicated would be the case, there was much more ilmenite."

Nuckols farm.—On this farm, located near Peers in Goochland County and about 8 miles south of the Bowe farm in Hanover County, similarly occurring rutile grains and large masses, intimately associated with ilmenite, are found loose on the surface and in the soil at a number of places, which will aggregate a considerable area in size. Some of the rutile masses are of unusual size, one piece being reported by Hess to have weighed between 200 and 300 pounds. Several masses of essentially pure rutile, exceeding 25 pounds in weight, were observed by the writers on the dump at one of the shafts. Many smaller masses were noted. Small grains and stringers of ilmenite are contained in some of the large masses of rutile (Pl. XXXVI, fig. 2).

The Nuckols farm has been more extensively prospected than the Bowe farm both by pits and several shafts not exceeding 75 feet in depth. The work was done by the Titanium Alloy Company of Niagara Falls. The rocks (pegmatite dikes) in which the openings are made show decay, chiefly kaolinization of the feldspars, to the entire depth reached by the shafts. The dikes are highly feldspathic bodies containing less quartz but variable in amount, with irregular distribution of rutile and ilmenite in grains and stringers similar to the occurrence on the Bowe farm (fig. 21).

COMMERCIAL POSSIBILITIES.

From the description detailed above, it is clear that the source of the rutile was in the pegmatite dikes cutting the gneiss. That which is found loose on the surface and in the soil was derived from the pegmatites by weathering. The commercial possibilities of the area, therefore, may be considered under (*a*) residual rutile found loose on the surface and in the rock decay (soil), and (*b*) unaltered pegmatite rutile.

Residual rutile.—In each locality studied, but more especially on the Bowe farm in Hanover County and the Nuckols farm in Goochland County, large quantities of rutile and some ilmenite, ranging from fine sand to masses weighing many pounds, occur loose on the surface and in the soil over many acres in extent. It would be extremely difficult if not impossible to accurately estimate the exact tonnage of this material, but there must be many hundreds of tons. Abundant water is close at hand for sluicing, so that the blanket or covering of loose rock decay could readily be worked by the usual methods employed in placer mining, and the rutile probably concentrated at a relatively small cost. Further cleansing of the rutile would probably require treatment by an electro-magnetic separator.

Pegmatite rutile.—The original source of all the rutile in the several areas of Hanover and Goochland counties has been from the rutile-bearing pegmatite dikes. That derived by weathering and found loose on the surface and in the soil has already been discussed. The present heading includes the rutile found in place in the pegmatite dikes cutting the gneiss below the mantle of residual rock decay.

It has been pointed out that prospecting has scarcely reached below the zone of rock decay, and that rutile with some ilmenite occurs in the pegmatites as small and large masses and streaks due to dynamic forces, and of unequal distribution. The occurrence of the rutile, including structure and mineral associates, has already been described. On the Nuckols farm in Goochland County, opalescent blue quartz with plagioclase feldspar and ilmenite, similar to the minerals associated with rutile in Nelson County, are observed with the pegmatite dikes in places.

While no definite law may be formulated as to the depth and position in the pegmatite dikes at which rutile bodies may be found it is regarded that as far as prospecting has extended the conditions are encouraging and fully warrant more careful and systematic development to determine whether the dikes contain commercial supplies of the mineral.

Conclusion.—It may be stated in summary that the writers regard the rutile occurrences in Hanover and Goochland counties as very promising. and that the conditions fully warrant more extensive and systematic exploratory work to determine whether commercial bodies of rutile are to be found in the unaltered pegmatites at depth. From our investigation of the area we are satisfied that there already exists a very considerable tonnage of rutile as loose grains and masses on the surface and in the soil that can be recovered at probably a minimum cost, when the local conditions favoring mining are considered. Moreover, we are led to suspect from the mode of occurrence of the rutile, etc., that systematic prospecting of the pegmatites at depth will possibly indicate a commercial supply of the mineral. It must be understood, however, that from the very mode of occurrence of the rutile, as described above, prospecting in the hard and unaltered pegmatite dikes is uncertain.

Sufficient prospecting has been done to indicate that the original occurrence of the ore was in the hard and unaltered pegmatite bodies of granitic composition. It has not been sufficient, however, to conclusively demonstrate the occurrence of rutile sufficiently concentrated to justify regular working. Whether additional prospecting should or should not prove workable ore to be present in the pegmatite bodies, a very considerable tonnage of rutile is readily available at present on the surface and in the residual rock decay (soil). So far as prospecting has extended, the openings indicate extreme irregularity of occurrence as to both quantity and distribution of the rutile in the pegmatite bodies.

CHARLOTTE COUNTY AREA.[a]

GENERAL STATEMENT.

In 1911, rutile was found by Joel H. Watkins in an area of metamorphic crystalline rocks, 12 miles northwest of Charlotte Courthouse, in the extreme northwest corner of Charlotte County. The area mapped, fig. 22, comprises two types of schist in their well-differentiated parts, but are regarded as probable variations of a single type, since they appear to grade into each other in the field, and with the exception of cyanite the principal minerals are the same in both. The rocks have a strike of N. 30° E. and an average dip of about 45° southeast, becoming vertical in places. No igneous rocks are found in the area, and it is distant about 15 miles from the exposed western margin of the granite and granite-gneiss belt.

The principal rock type is a thinly foliated quartz-sericite schist of light color and medium coarse grain, composed of quartz and sericite as the essential minerals, with occasional grains of rutile and other accessory minerals as microscopic inclusions. The second rock type is a cyanite schist of variable texture according to whether quartz or cyanite predominates. Some specimens show a fine-granular nearly white rock composed almost entirely of sugary quartz, with occasional cyanite and sericite. The other extreme is represented by a coarse aggregate of greenish cyanite in flat prismatic individuals measuring 2 inches long by 0.5 inch wide, and containing but little quartz. Between these two extremes many gradations are traceable. The principal minerals are quartz, cyanite, and sericite, with a goodly sprinkling of rutile in places. Black tourmaline and garnet are noted in places.

OCCURRENCE AND CHARACTER OF THE RUTILE.

The principal occurrence of rutile is in the cyanite schist although occasional grains are observed in the quartz-sericite schist. The rutile is frequently observed megascopically as minute grains in the hard rock and in the sands derived from the decay of the schists. It is red to reddish-brown, very faintly pleochroic, and the larger grains sometimes show cleavage. It is usually fresh, very seldom showing incipient alteration

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[a] Watson, Thomas L., and Watkins, J. H., Association of Rutile and Cyanite from a New Locality, Amer. Jour. Sci., 1911, vol. xxxii, pp. 195-201.

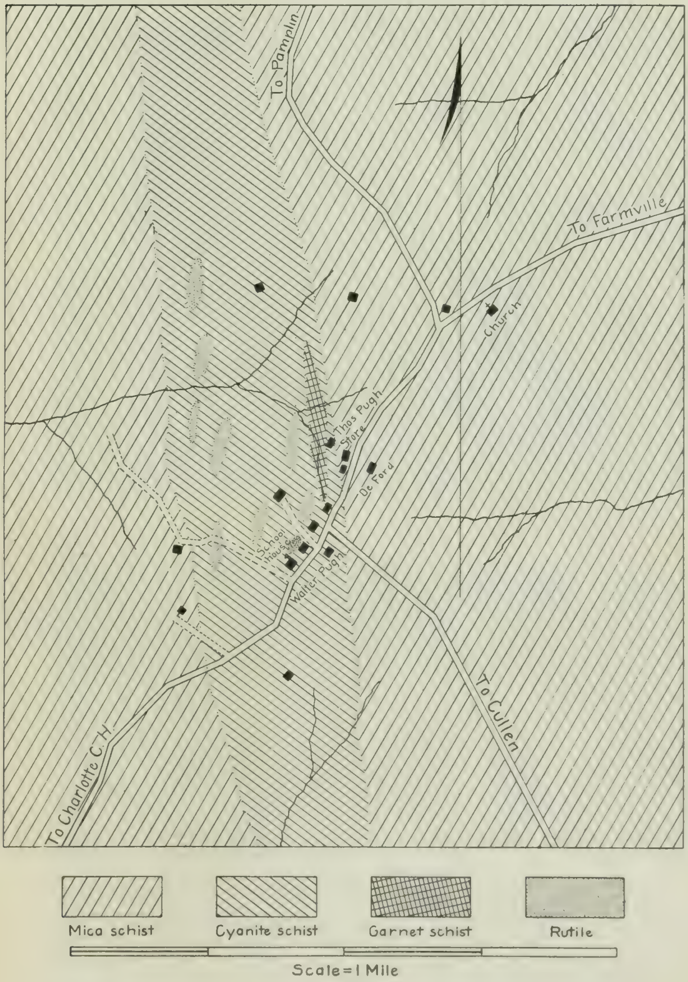

Fig. 22.—Geologic map of the Charlotte County, Virginia, rutile area.

peripherally to leucoxene. It is associated with both quartz and cyanite, more often with the latter, in euhedral and anhedral crystals, single and twinned, and sometimes in aggregates. In several thin sections rutile appeared to be as abundant in the quartz as in the cyanite.

Microscopically the rutile is usually inclosed in the substance of the cyanite and to some extent in the quartz. It is sometimes formed along the boundaries of the cyanite and quartz, frequently cutting into their substance; along cleavage directions in the cyanite; and occasionally along irregular fractures, but in such relations as to indicate that the rutile formed prior to the fracture of the cyanite. Plate XXXVII, figs. 1 and 2, make clear these relations of the rutile.

The rutile and other heavy metamorphic minerals associated with it in this area, are regarded as having been produced under conditions of dynamic regional metamorphism. The rutile is not known to occur in quantity in the Charlotte County area and is only of scientific interest.

BUCKINGHAM COUNTY AREA.[a]

At Willis Mountain, Buckingham County, rutile has been found in cyanite schists, the occurrence being closely similar to the Charlotte County area described above. Willis Mountain is a solitary monadnock which, rising abruptly from the average level of the Piedmont Plateau, reaches a height of 1,159 feet above sea-level and extends as a narrow ridge for a distance of about 2 miles in a north and south direction. The crest of the ridge is extremely rugged and precipitous, and is formed by a bare wall-like outcrop of cyanite schist. The dip of the strata is steeply toward the west.

The cyanite schist varies in texture according to the relative proportions of the two principal constituents, quartz and cyanite, and passes by gradation into the quartz-sericite schist with which it is interbedded. In places the rock is composed dominantly of cyanite in large bladed crystals, white to light gray or blue in color, and there are only minor amounts of quartz and sericite, the latter sometimes being practically absent; but elsewhere medium-grained saccharoidal quartz predominates with small prisms of cyanite scattered through the rock mass. Rutile occurs in small bright red grains disseminated indifferently through the other minerals. The only other constituent, prominent megascopically, is tourmaline, which may occasionally be distinguished in small black prisms.

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[a] Taber, Stephen, Geology of the Gold Belt in the James River Basin, Virginia, Va. Geol. Survey, Bull. No. VII, 1913, pp. 27-28, 113-114.

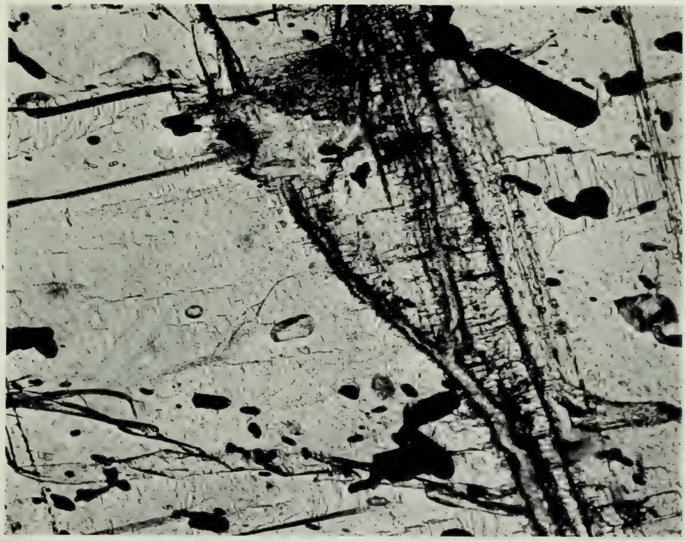

Fig. 1.—Cyanite with inclusions of rutile crystals from Charlotte County. Enlarged 105 diameters.

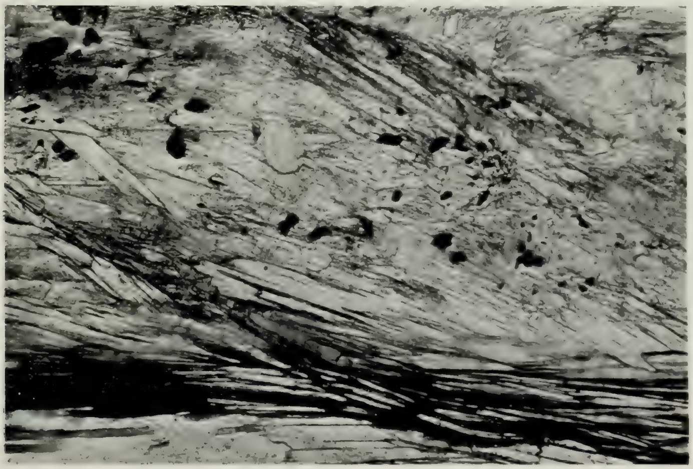

Fig. 2.—Cyanite altered to muscovite folia, with inclusions of rutile crystals shown. Charlotte County. Enlarged 105 diameters.

PHOTOMICROGRAPHS OF RUTILE IN CYANITE, CHARLOTTE COUNTY.

The cyanite crystals range up to 7 or 8 cm. in length and because of their resistance, stand out in relief on surfaces that have long been exposed to weathering. Under the microscope the mineral is colorless with good cleavage, frequently shows a slightly radiating texture, and there is occasionally a little alteration to sericite along cleavage planes. Rutile is commonly present as included anhedra which have their longer diameters oriented parallel to the principal cleavage planes in the cyanite.

The chemical composition of the rutile-bearing, cyanite schist, together with its structural relations, suggests that the rock was formed from a bed of very argillaceous sediments, possibly kaolin. The alteration took place under conditions of dynamic regional metamorphism and was doubtless aided by the intrusion of the large masses of granite which are found in the vicinity.

Another but less extensive outcrop of cyanite schist occurs 8 miles northeast of Willis Mountain. The rock is essentially similar to that just described except that it contains relatively less rutile. Neither occurrence is of any commercial importance.

ECONOMIC ASPECTS.

FUTURE OF RUTILE MINING IN VIRGINIA.

Rutile in very small amounts is of widespread occurrence, but it is very rarely found in sufficient quantity to be of economic importance. It is largely due to the scarcity of workable rutile deposits that so little effort has been made in the past to find uses for titanium and its compounds.

For many years the demand for rutile was very limited, and, while the prices were high, the consumption was not sufficient to encourage active search for new deposits or the extensive development of those already known.

Until the discovery and development of the Virginia rutile deposits, nearly all rutile sold for commercial purposes in this country was obtained from Chester County, Pennsylvania, though a small amount was recovered as a by-product in washing the monazite sands of the Carolinas. Picked specimens of rutile crystals were shipped from these states and from Magnet Cove, Arkansas, but they were sold entirely to museums and dealers in rare minerals. It is possibly due to the lack of crystal form in the Nelson County rutile that attention was not sooner drawn to the Virginia area.

In Europe the deposits at Kragerö, southern Norway, have been the chief source of rutile for many years, and have supplied most of the mineral used in the manufacturing industries.

The discovery of rutile in workable quantities has reduced the cost of titanium products and encouraged the search for new uses to which it might prove adaptable. The most promising uses so far announced are in the manufacture of ferro-titanium and of titanium carbide; the former being used in the production of special grades of steel, and the latter in making electrodes for arc lamps. The experimental tests that have been made with both of these compounds have proved highly satisfactory, and they have recently been placed on the market.

The manufacture of these compounds will necessitate an increased production of rutile, and the development of a large and steady demand should result in a material reduction in cost, since operation on a larger and more economical scale would then be possible. With a constant supply of rutile at reasonable cost, more uses for titanium may be expected to develop.

To supply the increasing demand there are only four known localities in the world that promise to be important factors in the production of rutile, and they are widely separated. Named in the order of importance from the standpoint of production these are: (a) The Amherst-Nelson counties area in Virginia, and a recently discovered area of promise in Goochland and Hanover counties in the same State; (b) the Kragerö area in southern Norway; (c) the Bay St. Paul area in northern Quebec, Canada; and (d) a recently discovered area 25 miles northeast of Adelaide in South Australia. The three foreign areas (b), (c), and (d) are described in some detail on pages 31-41 of this report.

In Norway, Kragerö is the only locality where rutile has been found in commercial quantity, and this does not approach the Virginia district in size. The rutile apparently contains more foreign material, is quite irregular in distribution, and can not be concentrated to give as high grade a product.

In the Bay St. Paul area, Quebec, Canada, the rutile is apparently quite pure in composition, but it is so irregularly distributed in small grains through masses of ilmenite or titanic iron ore in anorthosite as to render the area uncertain as a source of constant, large supplies of the mineral. This is increased by the fact that only a part of the ilmenite masses, so far as they have been studied, are rutile-bearing.

The rutile from South Australia is apparently very pure in composition, but, from what can be learned of its occurrence, it is probably by no means so extensive as the Virginia area.

In Virginia there is practically an unlimited supply of very pure rutile in the Amherst-Nelson counties area, which can be concentrated to yield a very high-grade product (over 99 per cent TiO_2). This area is the largest producer of rutile at present, and it will undoubtedly increase in importance in the future. The prospecting that has been done in the more recently discovered deposits of rutile in Goochland and Hanover counties, Virginia, encourages the belief that these may constitute an additional source commercially of the mineral in the State. With the development of new uses for titanium and the consequent increasing demand for rutile the future of rutile mining in Virginia is decidedly encouraging.

FUTURE DEVELOPMENT OF RUTILE MINING.

The writers believe that the rutile segregations in the syenite will prove to be more important as sources of rutile than the nelsonite dikes. The facts on which this statement is based are summarized below.

In the majority of the nelsonite dikes ilmenite largely predominates over rutile, although the latter is usually present in small amounts. In only two localities, the Giles tract and the Warwick farm, are exposures of nelsonite dikes found in which rutile is an important constituent. On the Giles tract the development work is insufficient to show the size of the ore-bodies and the average proportion of their constituents, but on the Warwick farm two dikes have been opened to a depth of 100 feet and for a distance of nearly 200 feet on the strike, while on the surface one of them has been proved by pits and trenches for about 500 yards. In these dikes the ratio of rutile to ilmenite is exceedingly variable, ranging from a rock made up almost entirely of rutile and apatite to one in which ilmenite is dominant and rutile practically absent.

The rutile-apatite ore-bodies are largely irregular masses that grade into the ilmenite nelsonite both in depth and along the strike of the dikes, and there is apparently no uniformity in their mode of occurrence. Since the rutile variety of nelsonite is an exceptional occurrence it is unlikely that it will be found in masses as large or as uniform in composition as the normal ilmenite nelsonite into which it grades. In mining such ore-bodies they are apt to pinch out or change to the normal type within comparatively short distances.

Practically all the syenite contains rutile in disseminated grains, but only in certain places is it segregated in quantity sufficiently rich to be workable. These segregations do not average as high in rutile content as the rutile-apatite (nelsonite) masses, but they are much more extensive and the rutile, after separation, is exceedingly pure, running in some instances over 99 per cent TiO_2.

Rutile derived from the syenite would be preferable in the manufacture of ferro-titanium, as extremely small amounts of phosphorus are detrimental to iron and steel, and the rutile concentrated from the nelsonite would necessarily contain small amounts of apatite unless removed by solution in acids. On the other hand, the apatite produced in mining rutile would be a valuable by-product.

Underground mining with its accompanying expense is the only method adaptable for extracting the nelsonite ore-bodies. The syenite segregations may be worked for years by means of surface cuts, and when this method is no longer practicable the "milling" process, or "glory-hole" method of mining may be resorted to, but it is believed that even cheaper methods would prove suitable for handling the decomposed portions near the surface.

The rocks of this region are, as a rule, covered by a mantle of residual decay and, as rutile is more resistant to the processes of weathering than the feldspar of the syenite, it is found in large quantities in the soil and decayed rock overlying the ore-bodies. These superficial deposits are often richer in rutile than the underlying rock from which they were derived, as the rutile has undergone a partial concentration by the removal of some of the lighter material with which it was originally associated. Some of these residual deposits could be worked to advantage by hydraulic methods of mining, as there is usually an abundance of water close at hand.

Kaolin and feldspar are possible by-products, for in some places the rutile-bearing syenite is found free from the ferro-magnesian minerals and contains very little quartz.

FUTURE PROSPECTING FOR APATITE.

Apatite is decomposed by weathering, and is removed in solution much more readily than ilmenite or rutile, and for this reason the surface exposures of nelsonite contain very little apatite, but are usually pitted by its removal. (Pl. XII, fig. 2.) Nelsonite, in which ilmenite or rutile largely predominates over apatite, would not fall to pieces upon the removal of apatite; it is nelsonite of this character that is found outcropping on the surface in many places over the area. On the other hand, a nelsonite dike in which apatite predominated would leave on weathering only black sand and would not be found exposed at the surface, though its presence might be indicated by an excess of black sand in the soil. For this reason it is believed that the ore-bodies richest in apatite are not to be found as surface exposures, but should be sought for at some depth below the soil covering.

They are more likely to be found within the borders of the syenite area, but near its contact with the country gneiss, and the presence of much black sand on the surface may often be considered a favorable indication. In prospecting for new ore-bodies there are many places where it would be advantageous to make use of drill-holes rather than surface trenches and shafts, as has been the custom in the past.

FUTURE OF APATITE PRODUCTION.

In the Lovingston district most of the magnetite-apatite (nelsonite) bodies that have been discovered are probably too low in apatite to be utilized. A number of irregular pockets and lenticular masses of nearly pure apatite have been opened, but, so far as developments show, they are too small in size to be profitably worked.

The nelsonite bodies in the Roseland district vary greatly in size, and in the percentage of apatite. In length they range up to 600 or 700 yards, as exposed on the surface, and in width up to 65 feet or more, but as yet few of the ore-bodies have been prospected in depth. The 60-foot shaft above Bryant Post-office, the shafts and drill holes of the Virginia Phosphate and Paint Company, near Roseland, and the shafts and 100-foot level of the General Electric Company's mine, represent the deepest development work thus far undertaken in the district. These ore-bodies have been found to a depth of at least 100 feet, but further exploration would undoubtedly show that the dikes continue to much greater depths. In the exposed dikes the percentage of apatite varies from 16 to 31 per cent, with occasional masses of nearly pure apatite, though these are few and small in size. The analyses given on page 147 show the range in phosphoric acid in the different ore-bodies. Samples taken from many localities indicate an average of about 23 per cent apatite for the upper portions of the dikes, but this percentage would undoubtedly be higher if samples could have been obtained at greater depths, where the rock has suffered less alteration.

At present it would not pay to work such ore-bodies for their apatite content alone, in competition with the phosphate rock of Florida, South Carolina, and Tennessee, which averages 70 to 80 per cent phosphate of lime, but the known phosphate desposits in this country are limited.

"The phosphate rock of South Carolina is nearly exhausted; the Florida deposits have probably reached their maximum production; the output of the Tennessee deposits is on the increase," but at the present rate of production, they probably can not, according to Van Horn, last for many years.[a] In addition to these localities from which nearly all the phosphate rock mined in the United States has in the past been obtained, there is a number of low-grade deposits scattered through the southern and middle west states, and within the last few years a large area of phosphate-bearing rock has been discovered in Wyoming, Idaho, and Utah. According to Van Horn, "the rate of increase in production for the last twenty years has been 117 per cent for each decade," and the increase in production will probably continue.[b]

When the high-grade phosphate deposits become exhausted the Nelson County, Virginia, apatite deposits (nelsonite bodies) may be profitably worked. If in the meantime some use for ilmenite on a large scale is found mining of the nelsonite bodies in the Amherst-Nelson counties area will at once become profitable, as the ilmenite can easily be separated from the apatite. One great advantage that the apatite deposits of this area have is their close proximity to the large pyrite bodies of Louisa County, which form one of the principal sources of sulphuric acid used in the manufacture of fertilizers.

USES OF TITANIUM AND ITS COMPOUNDS.

GENERAL STATEMENT.

Titanium compounds have long been used in limited quantities chiefly as a refractory coloring matter, but until recently the production of rutile, the principal commercial ore of titanium, was so uncertain that there was little inducement to develop industries dependent upon a steady supply. The discovery of rutile in workable quantities has encouraged the search for possible uses, and the development of the high temperature electric furnace for metallurgical purposes has made possible the reduction of titanium from its ores and the manufacture of many titanium compounds on a commercial scale.

Pure metallic titanium, because of its infusibility, has found little use in the arts and manufactures but, when alloyed with other metals and in various chemical compounds, it is rapidly coming into various uses of increasing importance.

The useful products into which titanium enters as an important constituent may be classified as follows:

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[a] Van Horn, F. B., Phosphate Rock, Mineral Resources of the U. S. for 1908, p. 640.

[b] Van Horn, F. B., Ibid., p. 639.

1. Metallic alloys, such as ferro-titanium and cupro-titanium.
2. Incandescent media for lighting purposes, including gas mantles, arc lamp electrodes, and filaments for incandescent electric lamps.
3. Mordants and dyes for leather and textiles.
4. Refractory coloring material for use in ceramics and the manufacture of artificial teeth.
5. Miscellaneous.

These products and their uses, as detailed below, have been compiled from private communications and all literature on the subject available to the writers. For any particular statement made in the text reference is given when possible to the original source of information. The principal references to the literature covering uses of titanium is given in the bibliography on pages 290-297.

1. METALLIC ALLOYS.

Alloys of titanium with various metals and several compound alloys have been made and their properties studied but, so far as known, ferro-titanium and cupro-titanium are the only alloys that have as yet been placed on the market. Ferro-titanium was one of the first to attract attention, its properties have been thoroughly tested and, within the past four years it has sprung into commercial importance as an agent for purifying iron and steel.

The introduction of titanium into the metallurgy of iron and steel should be credited very largely to Auguste J. Rossi who, for over thirty years, has devoted much of his time to the investigation of titaniferous iron ores and processes connected with their utilization. It has been generally held that the smelting of such ores is not economically possible at the present time, but this view has always been combated by Mr. Rossi,[a] and in proof he has sighted the furnaces that have successfully operated on titaniferous ores in Sweden, at Norton-on-Tee, England, and in the Adirondack Mountains of New York state. In Germany, Dr. Hans Goldschmidt, in his investigation of "aluminothermics," developed the first practical method of reducing titanium from its ores, and greatly advanced the use of the metal in metallurgical processes. It was the superior qualities of pig iron derived from titaniferous ores that led to the investigation of the influence of titanium on iron and steel, which resulted in the interesting and important discovery that the beneficial effect of that metal is almost entirely due to its high affinity for oxygen and nitrogen.

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[a] Rossi, A. J., The Metallurgy of Titanium. Trans. Amer. Inst. Mng. Engrs., 1902, vol. xxxiii, pp. 179-197.

It is well known that metals, while molten, have the property of absorbing considerable amounts of gas, most of which is expelled when the metal is allowed to cool and solidify. The oxygen and nitrogen taken from the atmosphere by iron in the process of smelting is partly combined with the metal, but largely separates out on cooling to form blow holes and other imperfections in the castings. The desirable physical properties of many special steels are very largely due to the reduction of oxides and removal of occluded oxygen by the addition of some element having a high affinity for that gas, but there are few elements possessing the power to combine with nitrogen and remove it from metals. Titanium unites with both oxygen and nitrogen to form stable compounds which are removed in the slag, the energy of combination resulting in the liberation of heat. Titanium also acts as a flux greatly increasing the fusibility of the slags.

Pig iron smelted from titaniferous ores contains only a very small amount of titanium, and it has been found that this is not present in the metallic state, but in combination with carbon and nitrogen as carbide, nitrides, etc. Since pig iron does not contain available titanium, and since even the little that may be present is removed in the process of refining iron for the purpose of making steel, the only way to secure the desired results in the finished product is to add it in some suitable form to the molten metal just before pouring.

There are two forms in which metal can be introduced into iron: (1) alone as pure metal, or (2) as an alloy with one or more other metals, ferro-alloys being the commonest. Owing to the great difficulties connected with the reduction of metallic titanium from its compounds, the cost of production would prohibit its use even though it were otherwise desirable, but experiment has shown that its employment is impracticable and that the use of ferro-titanium is in every way preferable. It is difficult to incorporate with the molten iron an alloy containing a high percentage of titanium, for the melting point of the alloy increases and its specific gravity decreases as the titanium content is increased. It is therefore advisable to use alloys containing low percentages of titanium, and in actual practice it is found that the best results are obtained with an alloy containing less than 25 per cent titanium. A 10 per cent titanium alloy is infusible at the melting point of cast iron and steel, but readily dissolves in a bath of the molten metal. The amount of ferro-titanium to be used varies with the grade of iron to be treated and the results desired, but in general it is found that one per cent or less is all that is necessary. The actual weight of metallic titanium, therefore, amounts to only about 2 pounds per ton of metal poured.

The addition of ferro-titanium is followed almost immediately by an increase in temperature of the molten metal, due to the energetic combination of titanium with the oxygen and nitrogen present. Stable oxides and nitrides are formed which rise to the surface and are removed as slag. All the titanium passes off with the slag unless more is added than the amount necessary to combine with the objectionable elements when the excess will remain in the metal. The presence of titanium in iron and steel produces no deleterious effects and may even improve the metal, but its chief value is entirely due to the removal of impurities and the prevention of segregation.

Ferro-titanium has been used in the production of high-grade pig iron and castings; it is successfully employed in the Bessemer and open hearth processes for making steel, and in the Tropenas, Roberts-Bessemer, and other modified processes; and it may be used to improve the quality of various crucible steels, such as the chrome, nickel, molybdenum, and tungsten steels.

In most of these processes it is the general practice to introduce the ferro-titanium in the casting-ladle after about one-third of the molten metal has run in; the alloy, broken into small pieces, being shoveled in cold while the metal is flowing. When filled the ladle is allowed to stand for a few minutes before pouring in order that the slag formed by the reaction may rise to the surface. When other agents, such as ferro-manganese or ferro-silicon, are used in the production of special steels they are introduced first, the ferro-titanium being the last added to the bath.

Iron treated with ferro-titanium has increased fluidity, the oxides and nitrides are removed with most of the slag, leaving a product that is stronger and more durable under shock and strain, and the castings are more easily machined, as they heat less under the tool. The depth of chill is raised but the chilled iron is harder and the transverse strength greater, which makes it especially suitable for the manufacture of car wheels, dies, die blocks, chilled rolls, etc.

The results of tests made by the United States Bureau of Standards, at Washington, on chilled test pieces made from strong car wheel iron, by the National Car Wheel Company, are tabulated below.[a] The titanium-iron was treated with one per cent of ferro-titanium.

The improvement in the quality of steel by treatment with ferro-titanium is even greater than that of cast iron; the oxides and nitrides are broken up and occluded gases removed, leaving the steel of greater

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[a] Information furnished by Charles V. Slocum.

RESULTS.

	Titanium Iron	Plain Iron
Height, inches	0.9967	0.9970
Compressed surface, inches	0.9977 by 0.9951	0.9969 by 0.9969
Ultimate strength, pounds per square inch	249,100	212,000
Approximate elastic limit, pounds	100,000 to 120,000	70,000 to 80,000

Applied Load	Length of sample	
0	1.0000 inch	1.0000 inch
10,000	0.9967 "	0.9970 "
75,000	0.9967 "	0.9969 "
80,000	0.9967 "	0.9967 "
85,000	0.9966 "	0.9963 "
105,000	0.9965 "	0.9954 "
115,000	0.9964 "	0.9949 "
120,000	0.9961 "	0.9945 "
130,000	0.9959 "	0.9938 "
150,000	0.9951 "	0.9923 "
180,000	0.9940 "	0.9886 "
200,000	0.9933 "	0.9836 "

density, closer grained, and free from blow holes and pin holes; the pipe is reduced and segregations practically eliminated; and castings are free from brittleness, heat less under the tool, and therefore may be machined more rapidly than other steels of the same carbon content. The use of ferro-titanium does not remove phosphorus and sulphur but, to a certain extent, it counteracts the objectionable effects of both elements. Phosphorus and sulphur form combinations with the iron and manganese and segregate out with the carbides, slag and other impurities, the tendency being to concentrate along the axis of the ingot near the top. Titanium increases the slag removed and by preventing segregation produces a more homogeneous material. Microscopic examinations of polished sections show very few slag inclusions, and when etched with cupro-ammonium or similar reagents the usual phosphorus and sulphur segregations are found to be surprisingly scarce. Chemical analyses of the different portions of an ingot give confirmatory proof of their homogeneity in composition.

Treatment with titanium alloy is found to raise the elastic limit of steel, increase the tensile strength, and at the same time increase its elongation and contraction. Tests made at the Watertown Arsenal, with the use of ferro-titanium in the manufacture of steel by the Tropenas process, show that the mean tensile strength was increased from 47,233 pounds per square inch to 50,000 pounds per square inch; that the mean elongation was increased from 15.1 per cent to 19.2 per cent; and that the mean contraction was increased from 18.9 per cent to 24.3 per cent.

The use of ferro-titanium in making Bessemer steel for rails has proved of the greatest importance. The first large scale experiments[a] with the alloy in this country were made at the works of the Maryland Steel Company, Sparrow Point, in November, 1907; several railroad companies began exhaustive tests of titanium rails in 1908; and during the year 1909, 35,945 tons of titanium rails were rolled in the United States,[b] while in 1910 the output increased to a total of 195,940 tons.[c]

The results of comparative tests made by the New York Central railroad, on a cross-over with 10 per cent curve carrying a heavy tonnage, showed that in 6 months the flange wear of titanium rails was less than one-third that shown by the ordinary Bessemer rails in 4 months; the loss being 1.103 pounds per yard for the titanium rail as against 3.59 pounds per yard for the Bessemer.[d] The rails weighed 100 pounds per yard and both kinds had the following average analysis:

	Per cent.
Carbon	0.452
Manganese	0.96
Silicon	0.13
Phosphorus	0.095

On October 7, 1908, the Baltimore and Ohio Railroad[e] laid 17 titanium rails and 7 Bessemer rails on Kessler's Curve of the Cumberland Division, West Virginia. This is a 9-degree curve of 6½-inch rail elevation, and both the grade and the traffic are heavy. All the rails were of the same weight, 100 pounds per yard, and they were distributed on both the high and low sides of the track. Diagrams of these rails were taken at intervals of two to three weeks. On July 8, 1909, after exactly 9 months of service, the average loss by wear from the Bessemer rails was greater by 294 per cent than for the titanium rails.

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[a] Titanium Rails, Railroad Age Gazette, Nov. 12, 1909, vol. xlvii, p. 904.

von Maltitz, Ed., The Effect of Titanium on Steel with Particular Reference to Rails, Stahl und Eisen, No. 41, 1909.

Slocum, Charles V., The Use of Titanium in Steel for Rails, Car Wheels, Etc., Electrochemical and Metallurgical Industry, 1909, vol. vii, pp. 128-130.

[b] Total Production of Rails in 1909, Bull. Amer. Iron and Steel Asso., March 1, 1910.

[c] The Iron Age, Feb. 23, 1911, p. 461.

[d] Titanium Rails, Railroad Age Gazette, Nov. 12, 1909, vol. xlvii, p. 904.

[e] Information furnished by Mr. Chas. V. Slocum.

The loss for the Bessemer rails varied from 2.970 pounds per yard to 7.029 pounds per yard, with an average of 4.861 pounds per yard. The analyses of these rails were as follows:

	Per cent.		
Carbon	.55	and	.54
Phosphorus	.068	"	.070
Manganese	.87	"	.83
Sulphur	.069	"	.073
Silicon	.092	"	.092

The loss for the titanium rails varied from 1.020 pounds per yard to 2.772 pounds per yard, with an average of 1.649 pounds per yard. The analyses of these rails were as follows:

	Per cent.		
Carbon	.701	and	.481
Phosphorus	.086	"	.075
Manganese	.92	"	.18
Sulphur	.048	"	.034
Silicon	.079	"	.099
Nitrogen	.004	"	.005

There was only one low manganese (0.18 per cent) rail laid and the loss, 1.881 pounds per yard in 9 months, would indicate that less manganese is necessary when the steel is treated with titanium.

In October, 1909, after one year of service, the titanium rails were still in good condition, and the durability test was being continued by comparing with a second set of standard Bessemer rails, the first set having been worn out and replaced. At this time the titanium rails showed more than 300 per cent increased durability over the Bessemer rails.[a]

The metallurgy of titanium and the method of making titanium alloys are described on pages 2-4 and 288-289. Ferro-titanium, unknown until recently, has suddenly assumed great importance and there is every reason to believe that it will be used hereafter in steadily increasing quantities in the manufacture of high-grade iron and steels.

In Europe the so-called ferro-titanium thermit[b] has been used instead of ferro-titanium to improve the quality of iron and steel castings. The "thermit" was developed by Dr. Hans Goldschmidt, and consists of an intimate mixture of powdered aluminum and the oxides of iron and titanium in the proper proportion to secure complete reduction of the oxides by the aluminum. This mixture, confined in a sheet-iron box on the end of an iron rod, is stirred into the molten metal, the temperature of which is sufficient to start the reaction; titanium is rapidly reduced by the aluminum, immediately combines with any nitrogen or oxygen present, and the cyanonitride of titanium, which is formed altogether with the oxides and other impurities, pass into the slag. The temperature of the molten metal is raised by the heat set free as a result of the reaction, and its fluidity is greatly increased. It is claimed to be particularly beneficial in cast iron. As a result of the increased fluidity the iron gives castings that are more dense and finer grained, a quality that is especially valuable for parts requiring a smooth finish, and which may be subjected to high pressures and great friction.

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[a] Electrochemical and Metallurgical Industry, 1909, vol. vii, p. 498.

[b] Goldschmidt, Hans, Aluminothermics, Electrochemical Industry, 1903, vol. i, pp. 527-534.

Rossi, A. J., Ferro Alloys; Their Uses in the Iron Industry, Cassier's Magazine, 1905, vol. 28, pp. 360-369.

An alloy[a] containing iron, titanium, silicon, and carbon has recently been introduced as an agent for refining steel. The titanium is believed to act chiefly upon the occluded nitrogen and the silicon upon the hydrogen and dissolved oxides. The alloy is added to the molten metal at the time of casting exactly as in the use of ferro-titanium. It is prepared in the electric furnace by either (1) the reduction with carbon of a charge containing the oxides of titanium and silicon, or (2) the reduction of titanium dioxide with carbon, ferro-silicon, or silicon being incorporated in the charge or added to the bath. The following is an analysis of a sample of the alloy:

	Per cent.
Iron	43.69
Titanium	33.70
Silicon	14.23
Carbon	8.32
Aluminum	0.08
Calcium	Trace

This alloy was patented,[b] in 1909, and as yet little has been made known relative to its production and properties.

Cupro-titanium, an alloy of titanium with copper, is used to improve castings of copper and brass, the procedure being practically the same as that employed in introducing ferro-titanium into iron and steel. Copper when molten very readily absorbs gases and becomes oxidized; upon cooling these gases are largely given off, producing, in some cases, ebullitions sufficiently violent to interfere with the process of making castings and leaving the product full of blow holes and imperfections. For this reason copper can not be cast in sand directly from crucibles, or in sand molds made in flasks, or such molds as are used for casting pig iron. The addition of a small amount of titanium in the form of a copper alloy is claimed to secure perfectly solid castings absolutely free from blow holes.[a] As manufactured at present the alloy contains from 5 to 12 per cent of titanium. Cupro-titanium was only recently placed on the market and as yet very little has been published relative to its use.

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[a] Electrochemical and Metallurgical Industry, 1909, vol. vii, p. 538.

[b] Letters of Patent Nos. 910,894; 940,665.

2. INCANDESCENT MEDIA.

The use of titanium in the metallic state, or in combination with other elements as incandescent media for lighting purposes, is one of the most important that has been developed. Titanium compounds have been employed in making mantles for gas lights, in the manufacture of electrodes for arc lamps, and in the formation of filaments for use in the incandescent electric lamp. Considerable experimentation and research work have been devoted to the perfection of the various titanium lights, but, from a commercial standpoint, the greatest progress has been made in the development of electric lights, especially the arc lamp. The value of titanium and its compounds as luminants is due to their high fusion and vaporization points, to their radiation efficiency and, in the case of arc lamps, to the spectrum furnished by titanium, which is one of the richest given by any of the elements so far as the number of lines is concerned.

A number of years ago one of the large electrical companies in this country began a series of experiments in order to ascertain what available material would give the maximum light efficiency when used as arc lamp electrodes. Many substances were tried, but it was found that those containing the element titanium gave the highest efficiency in candle power per watt consumed.[b] It is stated that as far back as 1878, Thomas A. Edison took out a patent in England for the use of titanium oxide (rutile) in arc lamps.[c] The first United States patent mentioning the use of any compound of titanium in the construction of arc-lamp electrodes was issued on February 18, 1890. In making the electrodes it was proposed to add to the carbon some difficultly fusible substance, such as titanic iron (ilmenite) in order to improve the steadiness and intensity of the light.

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[a] Electrochemical and Metallurgical Industry, 1909, vol. vii, p. 88.
Letters of Patent Nos. 700,244; 877,518; 905,232; and Reissue No. 12,764 granted to Auguste J. Rossi.

[b] Weedon, W. S., Trans. Amer. Electrochemical Soc., 1909, vol. xvi, pp. 217-227.

[c] Hess, F. L., Mineral Resources of the U. S. for 1907, pt. 1, p. 721.

For several years past, rutile has been quite extensively employed in the manufacture of the so-called magnetite arc-lamp electrodes, which, because of their long life and small cost of maintenance, give promise of superseding the enclosed carbon arc lamp for street lighting.[a] The cathode of the magnetite lamp consists of a mixture of the oxides of iron, titanium, and chromium which are present in the form of the minerals magnetite, rutile, and chromite. The magnetite particles make the arc stream a good conductor, but they are not very luminous; the high luminous efficiency is due to the incandescent particles of titanium oxide carried into the arc stream by the electric current; and the chromite is introduced to retard the rate of consumption and increase the life of the electrode. The rutile is finely powdered, and in quantity varies from 15 to 20 per cent of the mixture. The oxide of iron gives conductivity to the electrode when cold, the other oxides being conductors only when hot.

The advantages of the magnetite arc lamp as compared with the common carbon arc lamp are longer life, higher efficiency, and a better distribution and color of light. These lamps operating on a 4-ampere current, with approximately 67 to 70 volts, will give a light equal or superior to that of a 6.6-ampere, 75-volt direct current, enclosed carbon arc lamp.[b] The magnetite arc lamp can not be used on an alternating current system.

In January, 1907, a patent[c] was granted for an arc-light pencil consisting wholly or in part of an alloy of titanium with some metal, such as iron, possessing greater electrical conductivity. Such electrodes have been made directly from ferro-titanium, or from a mixture of magnetite and rutile, the oxides being subsequently partly reduced. The latter are said to give the best results. The light produced by these electrodes appears to the eye as yellowish-white in color. The spectroscope shows the entire spectrum with special brilliancy in the bright yellow portion, and the neighboring light green and orange. The size and length of the arc, which produces most of the light, soften the sharpness characteristic of the open carbon arc.[d] Among the advantages claimed are, greater durability, lower amperage required for the operation, and a light that will avoid the disproportion of red or other color lines objectionable in carbon pencils, approaching more closely the whiteness of sunlight; the so-called "crater" formed during the passage of a current in the positive carbon-electrode is eliminated, and the most intense heat and light are located at the upper surface of the negative electrode.

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[a] Barrows, W. E., Electrical Illuminating Engineering.

[b] Little, Geo. M., New Developments in Arc Lamp and High Efficiency Electrodes, National Electric Light Asso., Washington meeting, 1907.

[c] Letters of Patent No. 840,634.

[d] Ladoff, Isador, The Titanium Arc, Jour. Indust. and Eng. Chem., 1909, vol. 1, No. 10.

More recently a number of patents have been issued covering the use of titanium carbide (TiC), alone or mixed with other substances, in the manufacture of electrodes; and during the last few years much effort has been devoted to the perfection of this type of light. The best results are said to be obtained when the titanium carbide electrode is used as the cathode placed below an anode of copper, the latter being inactive and not wasting appreciably. In some of the lamps the anode is composed of carbon or of a shell of carbon containing a core made from a mixture of titanium carbide and carbon in the approximate ratio of 9 to 1.

The titanium carbide electrodes that have been used vary somewhat in composition, chiefly in the proportion of titanium carbide to carbon which is usually mixed with the former in making the electrodes. There are several grades of carbide on the market, some containing a little carbon in the form of graphite, some a small amount of metallic titanium or oxide of titanium, while others contain more or less iron. The first-named impurities are not especially detrimental, but it is desirable to free the carbide from any iron or silicates that tend to reduce the melting point of the electrode, as they interfere with the proper operation of the arc.

In one type of electrode the titanium carbide is surrounded by an iron tube, and in another the electrode is plated with copper; these devices being used in order to increase the conductivity and prevent oxidation during the burning of the lamp.

It has been found that titanium carbide electrodes permit a longer arc to be drawn for the same potential and current than corresponding electrodes of carbon, and that they are much more steady and smooth in action, being almost free from hissing and decrepitation. In a plain carbon arc nearly all the light radiates from the incandescent electrodes and very little light is given by the arc stream itself; the arc obtained from the titanium carbide, on the other hand, possesses an extremely luminous inner path, while little light is derived from the outer mantle, and none whatever from the electrodes. They are much more durable than the carbon electrodes.

The efficiency of the titanium arc is much greater than for the carbon and increases with increase in the current density, and with increase in the length of arc. At 3 amperes, 103 volts, and 1 inch arc length, 1,355 horizontal candle power has been obtained with an efficiency of 4.38 horizontal candle power per watt.[a]

Titanium suboxide has also been used in making electrodes, and, as with the carbide, it is preferable to use them for positive electrodes, while the negative electrodes are formed of some good conductor such as copper. These electrodes do not require any special treatment to increase their conductivity, as titanium suboxide is a good conductor of electricity at ordinary temperatures. The arc is almost identical in character with that of the carbide lamp and the light distribution is the same, but it is steadier in operation and has greater efficiency. The horizontal candle power at 3.4 amperes, seven-eighths-inch arc length and 100 volts is 2,100, with an efficiency of 6.17 horizontal candle power per watt. The chief objections to the suboxide electrodes are the somewhat rapid consumption and the formation of troublesome deposits on the anode. They can not be used with the alternating current.

With both the titanium carbide and the suboxide electrodes it is necessary to use a special starting device as a nonconducting layer of titanium dioxide tends to form at the tips which causes difficulty in starting after the lamp has once cooled down.

The titanium carbide used in the manufacture of electrodes is made from rutile by mixing the ore with an excess of carbon in the form of ground coke, and heating to the highest temperature obtainable in the electric furnace; the reduction of titanium dioxide and the formation of the carbide taking place at one operation. The furnace, which is of fire brick, is filled with a mixture of rutile and coke, and a heavy electric current is passed through the mass, the electrodes being placed in the center. Titanium carbide is formed only in the central portion of the furnace, the unreduced material surrounding it serving to prevent the entrance of air and the formation of nitrides. The product obtained is a porous honeycombed mass, silver white in color, that shows a tendency to crystallize in beautiful, small cubes the sides of which are hollow.

Titanium suboxide is formed by mixing 7 parts of rutile with one part of carbon and heating in the electric furnace. Its preparation is comparatively easy, since the melting point of the product is much lower than that of the carbide.

Incandescent electric lamps with filaments containing titanium have been placed on the market within the last few years, but because of the problems connected with the reduction of metallic titanium from its ores, the difficulty of drawing titanium wire, and its high affinity for oxygen and nitrogen, they have not been manufactured on an extensive scale. Experiments are now being conducted by several electric firms with the object of improving the methods of production and decreasing the cost of the lamps, and many patents have been issued in the United States and foreign countries covering the use of titanium in various forms as a component of incandescent lamp filaments. As yet little has been made public concerning the manufacture of these filaments.

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[a] Weedon, W. S., The Titanium Arc, Trans. Amer. Electroch. Soc., 1909, vol. xvi, p. 220.

The ordinary carbon filament of incandescent electric lamps is not an efficient light producer, as the greater portion of electrical energy is lost in the form of heat. This is because the filaments are destroyed when subjected to intense white heat by the conversion of the amorphous carbon of which they are composed into graphite of increased density. This alteration takes place gradually when they are heated to the lower temperatures in ordinary use, and finally results in breaking the filament. Titanium and many of its compounds remain unaltered at high temperatures, offer sufficient resistance to the passage of an electric current, and when heated to incandescence emit an intense light of high quality.

The melting point of titanium is said to be about 200° C. higher than tungsten, with a higher electrical resistance than that metal, so that its efficiency as a luminant is considerably greater. Filaments made of pure metallic titanium are capable of standing a much higher temperature than any form of carbon or its compounds. They must be used in a vacuum, or neutral gas, to prevent oxidation of the metal. It is claimed that they give a greater light for the same expenditure of energy than any form of electric luminant hitherto known, this being attributed to the better radiation from a smooth shiny surface, the high temperature coefficient, and the high temperature which the filaments can withstand.

Filaments of titanium alloys have been made in various ways; of the oxides of titanium alone, or combined with the oxides of other metals, and of titanium carbide and other titanium compounds.

As compared with lamps using the ordinary carbon filaments the titanium lamps have a greater length of life, a higher initial efficiency, and the decrease in efficiency is less throughout the life of the lamp. Because of their positive temperature coefficient the metal filaments have considerable inherent regulation so that the light is not as sensitive to the voltage variations of a badly regulated circuit. Moreover excessive voltages either momentary or continuous have less effect on the life of the lamp. In the metallic filament the current is greater at the instant of closing the circuit than it is a moment later but, in the carbon filament, the reverse is true. It is believed that the intense white light emitted by titanium filaments is due to selective radiation and temperature effect rather than preponderance of certain color lines.

3. MORDANTS AND DYES.

The first recorded attempt to utilize titanium compounds for coloring textiles[a] was made by an English firm about 10 years ago. Titanium ammonium oxalate was prepared from rutile by a rather tedious and complicated process but the cost of manufacture, together with the high price of titanium ore at that time, made the product most too expensive for ordinary commercial use.

On December 5, 1896, H. W. Kearns and Dr. Barness applied for a patent on the use of titanium and tannic compounds for coloring vegetable fibres. Dr. Franz Erben[b] proved that a fibre treated with a tannin compound and then with titanium ammonium oxalate was given a saturated golden yellow color of great durability, able to withstand the action of boiling and washing. The color produced in this way is said to be superior to that obtained by the action of chlorinated primaline and even the best sulphur colorings. Any desired shade of yellow or orange can be secured by the addition of auranein G or O, acid orange or similar products, and many other colors such as red, green, blue, etc., may be improved by the use of a tannin-titanium base with various basic coloring matters.

Several other titanium salts have been used in a similar way, but at present titanium potassium oxalate ($TiOC_2O_4K_2C_2O_4.H_2O$) is probably more extensively used as a mordant and dye in the textile industries than any of the others. It is obtained in fine white crystals which do not alter on keeping and which are readily soluble in warm water, giving a clear solution.

Used alone the titanous salts act as powerful mordants, yielding fast bright colors intermediate in shade between those produced by chromium and aluminum. These colors are far brighter and clearer than the shades obtained from chromium salts, while they have equal and in some cases greater fastness to light, washing, milling, etc. As compared with chromium salts the principal advantages of titanium are as follows:

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[a] Ladoff, Isador, The Technical Application of Titanium, Jour. Indust. and Eng. Chem., 1909, vol. 1, pp. 642-644.

[b] Chem. Zeit., No. 14, 1905.

(a) The dyeing may be done in a single bath exactly as with acid dye.

(b) The colors produced are so bright that compound shades may be obtained by mixtures of mordant dyes, which are as bright as compound acid dye shades while possessing the fastness characteristic of the mordant dyes.

(c) When the mordant colors are used with chromium it has not been possible to obtain light, pale shades, but with titanium all shades down to the very palest pinks and blues may be produced in the single bath process.

Titanium compounds are now successfully used, both in this country and in Europe, as mordants and dyes for wool, cotton, and similar textiles, and they may also be used in the same way to color and mordant paper or paper pulp.

Titanous chloride ($TiCl_3$) and titanous sulphate ($Ti_2(SO_4)_3$) have recently been introduced in the texile coloring industries, and are now manufactured on a commercial scale in the United States and Europe. It is claimed that they are the most powerful soluble acid-reducing agents known, being far more efficient than stannous chloride, which has hitherto constituted the best acid-reducing agent for use in dyeing and printing textiles.

In textile printing titanous salts may be used either for discharge or for resist work. They are especially useful for discharging the direct colors and readily act on such colors as chrysophenine, which are scarcely affected by stannous chloride.

These salts are also used as stripping or bleaching agents. In dyeing textiles such as cotton, wool, and silk it sometimes happens that a wrong shade is produced or that the dyeing takes place unevenly. When this occurs it is necessary to either strip and re-dye, or dye a darker shade. For stripping, the ordinary bleaching agents, such as bleaching powder or hypochlorite of soda, are not suitable for most colors, since they would have to be used in such concentration as to make the injury of the goods probable. If such dyed goods are run through a hot dilute solution of one of the titanous salts the destruction of the color takes place in less than one minute without injury to the material, which may be washed and then re-dyed. Titanous salts, in very dilute solutions, are used to clear up the white portions of fancy colored goods.

A double compound of titanous sulphate (sesquisulphate) and sodium sulphate, of the composition (after drying in a vacuum) $Na_2SO_4Ti(SO_4)_3$.-

$5H_2O$, has been produced. It is said to be a powerful reducing agent, especially suitable for use in the textile industry.[a]

The double pyrophosphates of titanium and an alkali metal have recently been obtained and a patent granted covering their use. These double salts may be applied to textiles and other substances without injury to the texture or material.[b]

Titanium salts are now employed in both Europe and America as mordant and dye in the manufacture of leather goods, having proved of especial value for use on chrome tanned leathers. Potassium titanium oxalate is the salt that has found the most extensive use for this purpose. It serves as an excellent direct dye for tanned leathers, producing a fast yellowish-brown color, unaffected by light, alkaline salts or rubbing, and therefore especially suitable for shoe leather. This yellow-tan shade may be modified by varying the tannin material and by the addition of other dyes.

Potassium titanium oxalate fixes the tannin in the leather by forming an insoluble yellowish-brown titanium tannate on the fibre of the material, and is a great improvement over tartar-emetic which has hitherto been used for this purpose. The color obtained in this way forms an excellent base for the production of other colors except bright blues, with which the yellow color of the titanium tannate interferes. Other mordants, such as the similar antimony salt which has formerly been used to fix the tannin in leathers, give no color. Therefore when it is desired to produce a compound color in which yellow enters as a component a large saving in time and dyestuffs results from the use of titanium mordant.

On chrome tanned leather potassium titanium oxalate used as a mordant for dyewood colors gives the following shades:

With Fustic Extract, a yellowish-brown.
With Lima Extract, a bluish-red.
With Cuba Extract, a light brown.
With Sumach Extract, a lemon yellow.
With Logwood Extract, a violet and a black.

By judicially mixing the dyewoods an unlimited number of shades can be obtained. Titanium potassium oxalate used as a striker for logwood gives an intense black, which is much better as to color and durability than the black produced when iron salts are used. The iron acts as an oxygen-carrier, and gradual oxidation of the leather finally renders it brittle. Titanium salts do not have this deleterious effect on leathers, and therefore the black leathers produced from titanium have a greater durability.[c]

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[a] Titanous Compound and Process of Making Same, Electroch. Industry, 1904, vol. ii, p. 239.

[b] London Mining Journal, July 13, 1907, p. 65.

[c] Titanium Mordants, Shoe and Leather Reporter, 1908, pp. 19-20.

In the dyeing of vegetable tanned leathers there is a wide field for the application of titanium salts in the production of fast colors, almost any shade being obtainable by mixing the proper dyes.

Titanium oxalate and the double tartrates and lactates of titanium and the alkali metals are also used in leather dyeing.

Titanium ferrocyanide is employed as a substitute for the poisonous Schweinfurth green and other arsenical pigments.[a]

The logwood titanium compound makes a permanent ink, deep black in color, which undergoes no change after using.

4. REFRACTORY COLORING MATERIAL IN CERAMICS, ETC.

In the porcelain industry rutile is used to give a beautiful, soft yellow color under the glaze. The best effects in muffle colors do not compare in depth and richness with those produced under the glaze, for in firing the glaze and the pigment fuse together, producing a softness of coloring that may be obtained in no other way. Under-glaze painting is a part of the ware itself and not a coating that may crack or peel off; the finished product is perfectly smooth and does not present the rough, slightly raised surface characteristic of muffle colors.

The choice of colors which may be used for painting on porcelain after firing is very large, and gives every color and shade that could be desired; but the list of colors available for under-glaze painting is extremely limited, for the high temperature maintained while firing destroys all but the most refractory pigments. Only three of the substances used in porcelain decoration, upon the biscuit or under the glaze, give a yellow color, namely, the compounds of uranium, and the oxides of iron and titanium. Uranium is a rare metal and its compounds are too expensive for ordinary use; the oxide of iron has not proved entirely satisfactory and the color produced admits of little variation in tone or shade; the titanium oxide (rutile) has none of these disadvantages, though great care is necessary in order to obtain the desired results.

Rutile used alone imparts to porcelain a fine yellow color, the exact shade depending on the quantity; it may be employed with other substances to produce various secondary colors; and it is not affected by the temperature of the kiln, although it slightly lowers the fusing point of the porcelain when much of it is used. When it is desired to use large quantities of the pigment the fusing point might be raised by decreasing the proportion of feldspar. Unless care is taken to shield porcelain products, while in the furnace, from the action of reducing gases, the rutile (TiO_2) will be reduced to titanous oxide (Ti_2O_3), which imparts a deep copper-red color to the ware.

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[a] Baskerville, Charles. The Rare Metals. Eng. and Mng. Jour., 1909, vol. lxxxvii, pp. 10-11.

In the manufacture of artificial teeth rutile is used to give the required color, but for this purpose only the purest grades of finely ground material can be employed. The production of artificial teeth in the United States has been estimated to reach 8,000,000 annually, and in all of these titanium dioxide is the pigment used. The teeth are moulded from a paste composed of kaolin, feldspar, silica, and rutile, the proportions by weight being approximately kaolin 6 per cent, silica 19 per cent, and feldspar 75 per cent, while the amount of rutile varies from 0.5 per cent up to several per cent according to the color desired.[a]

5. MISCELLANEOUS USES.

Among other uses for titanium products may be mentioned the following:

Titanium sesquioxide (Ti_2O_3) and its salts are employed as reducing agents for various purposes, especially in the textile industry. Sodium titanous sulphate ($Ti(SO_4)_2Na_2SO_4.3H_2O$) and titanous chloride ($TiCl_3$) have been found most useful.

Titanium dioxide has been used in the manufacture of a protective paint for iron and steel.

Titanous sulphate is said to be the strongest acid-reducing agent now known, reducing chinon to hydrochinon, and throwing copper and silver instantaneously out of solution quantitatively as metal.[b] It is obtainable in the form of a solution, deep violet in color, and is used to decolorize old paper, dyed fabrics, and other discolored matter.

In analytical work titanium sulphate ($Ti(SO_4)_2$) may be employed in determining the presence of fluorine. A solution of titanium sulphate oxidized by hydrogen peroxide gives a wine-colored liquid, and the degree of decolorization produced by addition of fluorine indicates the amount of fluorine present. This method is accurate for very small quantities.[c]

Because of the beautiful light effect produced by titanium during combustion it has been used in pyrotechnics.

It has been proposed that titanium nitride be used as a basis for fertilizers and other nitrogen compounds, and patents have been issued covering the manufacture of titanium nitride as a by-product in the smelting of titaniferous iron ores. The titanium nitrides yield ammonia when heated in hydrogen, and the reaction for the formation of Ti_5N_6 and other titanium nitrides might be used as the basis of a process for obtaining ammonia from atmospheric nitrogen; but this interesting application has not been employed technically.[a] Moissan found that Ti_2N_2 has a hardness greater than that of the ruby and sufficient to slowly polish diamonds.[b]

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[a] Snelling, W. O., Titanium Ores, Mineral Resources of the U. S. for 1901, pp. 271-278.

[b] Zeitsch. Phys. Chem., 1908, vol. 62, p. 147.

[c] Hess, Frank L., Mineral Resources of the United States for 1906, p. 530.

Sometimes crystals of rutile are found sufficiently clear for gem purposes.

METHODS OF PREPARING TITANIUM ALLOYS.

Ferro-titanium.—Ferro-titanium was first prepared by reducing the oxides of iron and titanium with carbon in an electric furnace. Titanium oxide is not reduced by carbon at the temperatures attainable in the blast furnace, but requires the high heat of the electric furnace for its reduction. Titanium alloys made by this method unavoidably contain from 5 to 9 per cent carbon, which is present partly as graphite and partly in the form of carbides, and while this is not objectionable for some purposes it is for many others, where it is necessary to use an alloy containing less than one per cent carbon. It is possible by subsequent treatment to free these alloys from a large part of their carbon, but, in most cases, it is very difficult to reduce it to the admissible limit, and the cost is prohibitive when working on a commercial scale.

Two methods have been employed in the manufacture of ferro-titanium, practically free from carbon, both of which depend on the strong reducing action of metallic aluminum. These methods are known as the Goldschmidt, or "alumino-thermic" process, and the Rossi process; the former was developed by Dr. Hans Goldschmidt, and is used principally in Europe; the latter by A. J. Rossi, and is employed in this country in the manufacture of ferro-titanium and other alloys.

In the Goldschmidt process the metallic oxides to be reduced are mixed with aluminum in proper proportions, both being finely powdered; then, by means of a fuse, some point within the mixture is brought to the temperature at which aluminum combines with oxygen, after which the reaction continues without the addition of external heat, the reduction taking place almost instantaneously. The chief objections to this method are the high cost of powdered aluminum, and the difficulty of obtaining a complete reduction and a pure product when the reaction takes place with such rapidity.

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[a] Baskerville, Charles, Personal communication.

[b] Moissan, H., Ann. Chim. Phys., vol. vii, p. 229.

In the process developed by Mr. Rossi the reduction takes place in a bath of aluminum. The aluminum in ingots or any other form is melted down in an electric furnace, and the required amount of pig iron or good scrap iron added to the charge. Rutile is now introduced into the bath of molten metal and the temperature raised to a point sufficiently high to start the reaction by which the aluminum combines with the oxygen of the rutile, the latter being reduced to metallic titanium which immediately alloys with the iron.

Ilmenite or titanic iron ore may be used in the place of rutile and metallic iron in the manufacture of ferro-titanium, but this increases the cost of the process by the amount of aluminum necessary to reduce the iron oxide, which can be reduced much more economically in other ways, and it is more difficult to control the composition of the resulting alloy. Rossi was able to obtain alloys high in titanium from ilmenite by smelting in an electric furnace with sufficient carbon to reduce the iron oxides, but not the titanium oxide; the latter combining with lime and silica to form a slag high in titanium content, which was subsequently treated in a bath of aluminum and the titanium reduced in the manner described above. The use of ilmenite in the place of rutile is only justifiable when the cost of rutile is so high as to exceed the increased cost of manufacture resulting from the greater consumption of aluminum.

Cupro-titanium.—Cupro-titanium is manufactured by the Rossi process, the rutile being reduced in a bath of aluminum to which copper has been added to alloy with the metallic titanium. The method is similar in every way to that described for the production of ferro-titanium by the same process. In making this alloy it is necessary to use rutile as the source of titanium, since ilmenite can only be used when the resulting alloy may contain iron.

Carbon is now used exclusively as the reducing agent for titanium at the Niagara Falls plant of the Titanium Alloy Manufacturing Co., replacing the aluminum bath method formerly in use. It is a secret process, but there are patents covering the furnaces, furnace lining, etc. Magnetite lining is said to be used.

There is still some of the ferro-titanium manufactured by the aluminum process in stock, and it can be distinguished from the new product obtained by the use of carbon by the fact that the former is smooth and shiny while the latter is rough.

Experiments to improve and reduce the cost of manufacture of cupro-titanium are still in progress. It is not certain whether this product is now on the market or not.

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INDEX

Acknowledgments, xvi.
Age relations, 230–231.
  ore deposits of the Roanoke County area, 247.
  rutile deposits, 258.
Alabama, 22–23.
Allanite and sipylite, 233.
Alteration of rutile, 17–18.
American Rutile Company's quarries, 161–173.
  Composition of rutile concentrates, 172–173.
  Geological relations, 163–170.
  Location and history, 161–162.
  Mining and milling operations, 170–172.
  Production and uses, 163.
Amphibole (uralite), 219–222.
  Analysis and ratios of, 219.
  Composition and optical properties, 219.
  Uralitization, 220–222.
Amphibolite, 199–200.
An exceptional facies, 130–133.
Analyses and ratios of ilmenite, 225.
  biotite-quartz monzonite-gneiss, 63.
  diabase, 158.
  gabbro-nelsonite, 140.
  gabbros, 95.
  hornblende nelsonite, 135.
  magnetite and biotite nelsonites, 125.
  nelsonites, 147.
  rutile, Graves Mountain, 26.
  rutile nelsonite, 120.
  syenite, 76.
  syenite and nelsonite rutile, 227.
  tailings from American Rutile Company's ore, 171.
Analysis and norm of bergenose from Norway, 142.
  ratios of hornblende from Nelson County, 219.
  ratios of hypersthene, General Electric Company's mine, 218.
  apatite, General Electric Company's mine, 189.
  apatite from nelsonite, General Electric Company's mine, 108, 223.
  hypersthene akerite, Milam's Gap, 239.
  ilmenite, General Electric Company's mine, 191.
  ilmenite from nelsonite, General Electric Company's mine, 107.
  ilmenite nelsonite, 109.
  kragerite (rutile aplite), Kragerö, Norway, 40.
  kragerite rutile, Kragerö, Norway, 40.
  nelsonite rutile, 197.
  rutile from Black Hills, 30.
  rutile from General Electric Company's mine, 190.
  rutile nelsonite from General Electric Company's mine, 119.
  rutile from syenite near Roseland, 194.
  rutile from St. Peter's Dome, 30.
  rutile from West Cheyenne Canon, 30.
  rutile-sapphirine-bearing ilmenite, St. Urbain, 33.
Apatite, 222–223.
  Analysis of, General Electric Company's mine, 223.
Areal distribution, 58–59.
Areal geology, 176–193.
  Diabase, 192–193.
  Gabbro, 191–192.
  Introductory statement, 176–179.
  Nelsonite, 184–191.
  Syenite, 179–183.
Arkansas, 29.
Australia, 34–36.
  Queensland, 34–35.
  South Australia, 35–37.
Bibliography on titanium, 290–298.
Biotite, 222.
Biotite gneiss, 198–199.
Biotite-quartz monzonite-gneiss, 59–68.
  Chemical composition and classification, 63–66.
  Distribution and lithologic characters, 59–61.
  Microscopic character, 61–63.
  Quartz veins, 66–68.
Bowe farm, 258–259.
Buckingham County area, 264–265.
California, 29.
Canada, 31–34.
  Nova Scotia, 34.
  Ontario, 34.
  Quebec, 31–34.
  Yukon territory, 34.
Carolinas, 27–28.
  North Carolina, 27–28.
  South Carolina, 28.
Cassiterite (tin ore), 233.
Charlotte County area, 262–264.
  General statement, 262.
  Occurrence and character of the rutile, 262–264.
Chemical characters, 203–210.
  Table of analyses of silicate rocks, Nelson County, 204, 205, 206.

  Table of averages of analyses of silicate rocks, Nelson County, 207.
Chemical composition, 75–78, 145–148.
  Analyses of nelsonites, Nelson County, 147.
  Analyses of syenite, 76.
  Feldspar composition of syenite, 77–78.
  Norms of nelsonites, 148.
Chemical composition and classification, 40–41, 63–66, 94–100, 109–110, 120–122, 124–127, 135–137, 140–143, 157–159.
  Analysis and norm of bergenose, Norway, 142.
    ilmenite nelsonite, 109.
    kragerite (rutile aplite), Kragerö, Norway, 40.
  Analyses of biotite-quartz monzonite-gneiss, 63.
    diabase, 158.
    gabbro-nelsonite, 140.
    gabbros, 95.
    hornblende nelsonite, 135.
    magnetite and biotite nelsonites, 125.
    rutile nelsonite, 120.
  Norms, 41, 65, 96, 109, 121, 127, 135, 141, 148, 158.
  Table of feldspar composition, 63.
Chemistry, 1–4.
  General properties, 1–2.
  Methods of preparation, 2–4.
Classification, 78–80, 148–151.
  Nelsonites compared with titaniferous magnetites, 150.
  New quantitative system of, 148.
  Norms of syenite, 78.
  Old system of, 148.
  Quantitative, of titaniferous magnetite ores, 151.
  Summary of quantitative, 78–80.
Classification of nelsonites compared with titaniferous magnetites, 150.
Colorado, 29–30.
  Analysis of rutile, St. Peter's Dome, 30.
  Analysis of rutile, West Cheyenne Canon, 30.
Commercial analyses of rutile concentrates, American Rutile Company's property, 173.
Commercial possibilities, 260–261.
  Conclusion, 261.
  Pegmatite rutile, 260–261.
  Residual rutile, 260.
Comparison with syenite of northern Blue Ridge, Virginia, 239–240.
  Analysis of hypersthene akerite, Milam's Gap, Virginia, 239.
Composition and optical properties, 218, 219.
Composition, apatite, 189.
  ilmenite, 190, 224.
  rutile, 190, 194, 197.
  rutile concentrates, 172–173.
Compounds of titanium, 4.
Conclusion, commercial possibilities, 261.
Connecticut, 19–20.
Contacts, 84–90.
  Gneiss-syenite contact on the northwest side, 86–90.
  Gneiss-syenite contact on the southeast side, 84–86.
  Mars Mountain, 90.
Cupro-titanium, 289.
Davis Creek district, 44.
Detailed description, nelsonite occurrences, 184–191.
  Composition of apatite, 189.
  Composition of ilmenite, 190.
  Composition of rutile, 190.
Detailed description, syenite occurrences, 180–183.
Details of occurrences, diabase, 159–160.
  gabbro-nelsonite, 143–145.
  ilmenite nelsonite, 111–117.
Diabase, 155–160, 168–170, 192–193, 246, 254.
  Chemical composition and classification, 157–159.
  Details of occurrences, 159–160.
  Distribution and lithologic characters, 156.
  Introductory statement, 155–156.
  Microscopic character, 156–157.
Diorite, 253–254.
Distribution, 59, 70, 91, 101, 106.
Distribution and lithologic characters, 59–61, 156.
  Distribution, 59.
  Lithologic characters, 59–61.
Distribution and occurrence of titanium, 12–13.
Districts (subdivisions), 42–44.
  Davis Creek district, 44.
  Lovingston district, 44.
  Roseland district, 42.
Economic aspects, 265–270.
  Future development of rutile mining, 267–268.
  Future of apatite production, 269–270.
  Future of rutile mining in Virginia, 265–267.
  Future prospecting for apatite, 268–269.
Economic considerations, 258–261.
  Commercial possibilities, 260–261.
  Mining developments, 258–260.

Feldspar, 216–217.
Feldspar composition of syenite, 77–78.
Ferrates, 8–9.
  Magnetite, 8–9.
Ferro-titanium, 288–289.
Ferruginous conglomerate, 234.
Field work, xv.
Future, apatite production, 269–270.
  rutile mining in Virginia, 265–267.
Future development of rutile mining, 267–268.
Future prospecting for apatite, 268–269.
Gabbro, 91–100, 165–168, 191–192.
  Chemical composition and classification, 94–100.
  Distribution, 91.
  Megascopic character, 91–92.
  Microscopic character, 92–94.
Gabbro-nelsonite, 138–145.
  Chemical composition and classification, 140–143.
  Details of occurrences, 143–145.
  Megascopic character, 138–139.
  Microscopic character, 139–140.
  Name and distribution, 138.
Galena, 232.
General character, 237–240, 255–256.
  Ilmenite, 256.
  Megascopic character, 255.
  Microscopic character, 255–256.
General description, 38.
General Electric Company's mine, 173–193.
  Areal geology, 176–193.
  General statement, 173–175.
  Mining developments, 175–176.
General geology and petrography, 56–160, 250–258.
  General statement, 56–57.
  Introductory statement, 250.
  Principal rock groups, 57–160, 251–258.
General microscopic characters, nelsonite, 104–105.
General petrology of the Amherst-Nelson Counties region, 202–234.
  Age relations, 230–231.
  Chemical characters, 203–210.
    Table of analyses of silicate rocks, 204, 205, 206.
      average of analyses of silicate rocks, 207.
  Geologic occurrence, 202–203.
  Introduction, 202.
  Mineralogical characters, 213–231.
    Amphibole (uralite), 219–222.
      Analysis and ratios of hornblende, 219.
      Composition and optical properties, 219.
      Uralitization, 220–222.
    Apatite, 222–223.
      Analysis of apatite, 223.
    Biotite, 222.
    Feldspar, 216–217.
    Graphite, 229–230.
    Ilmenite, 223–226.
      Analyses and ratios of ilmenite, 225.
      Composition of ilmenite, 224.
    Introduction, 213–214.
    Magnetite, 223.
    Olivine, 222.
    Other minerals, 230.
    Pyroxene (hypersthene), 217–219.
      Analysis and ratios of hypersthene, 218.
      Composition and optical properties, 218.
    Quartz, 214–215.
    Rutile, 226–229.
      Analyses of syenite and nelsonite rutile, 227.
      Possible effect of vanadium on color of rutile, 228.
        Partial chemical analyses of rutile, 228–229.
  Miscellaneous minerals, 231–234.
    Ferruginous conglomerate, 234.
    Introductory statement, 231.
    Minerals occurring beyond the limits of the mapped area, 233.
      Allanite and sipylite, 233.
      Cassiterite (tin ore), 233.
    Minerals occurring within the mapped area not previously described, 231–233.
      Galena, 232.
      Graphite, 232.
      Kaolin, 232–233.
      Sphalerite, 231–232.
  Norms of Amherst-Nelson counties rocks, 210–213.
    Norms of ore rocks (nelsonites), 212.
    Norms of silicate rocks, 210–211.
    Summary of classification, 211.
  Textural characters, 230.
General properties, 1–2.
General statement, 18–19, 56–57, 68–69, 161, 173–175, 193, 236–237, 241, 262, 270–271.
Genesis, 151–155, 246–247, 257–258.
  Table of melting points of rutile, ilmenite, and apatite, 154.
Geographic distribution of rutile, 18–41.
  Australia, 34–36.

  - Canada, 31–34.
  - General statement, 18–19.
  - Norway, 37–41.
  - United States, 19–31.
- Geologic occurrence, 202–203.
- Geological relations, 163–170.
  - Diabase, 168–170.
  - Gabbro, 165-168.
  - Syenite, 163-165.
- Geology and ore deposits, Amherst-Nelson counties region, 42–160.
  - Districts (subdivisions), 42–44.
    - Davis Creek district, 44.
    - Lovingston district, 44.
    - Roseland district, 42.
  - General geology and petrography, 56–160.
    - Areal distribution, 58–160.
      - Biotite-quartz monzonite-gneiss, 59–68.
        - Chemical composition and classification, 63–66.
          - Analyses of biotite-quartz monzonite-gneiss, 63.
          - Norms, 65.
          - Table of feldspar composition 65.
        - Distribution and lithologic characters, 59–61.
          - Distribution, 59.
          - Lithologic characters, 59–61.
          - Microscopic character, 61–63.
          - Quartz veins, 66–68.
      - Chemical composition of nelsonites, 145–148.
        - Analyses of nelsonites, 147.
        - Norms of nelsonites, 148.
      - Classification, 148–151.
        - Classification of nelsonites compared with titaniferous magnetites, 150.
        - New quantitative system of classification, 148.
        - Old system of classification, 148.
        - Quantitative classification of titaniferous magnetite ores, 151.
      - Diabase, 155–160.
        - Chemical composition and classification, 157–159.
          - Analyses of diabase, 158.
          - Norms, 158.
        - Details of occurrences, 159–160.
        - Distribution and lithologic characters, 156.
        - Introductory statement, 155–156.
        - Microscopic character, 156–157.
      - Gabbro, 91–100.
        - Chemical composition and classification, 94–100.
          - Analyses of gabbro, 95.
          - Norms, 96.
        - Distribution, 91.
        - Megascopic character, 91–92.
        - Microscopic character, 92–94.
      - Gabbro-nelsonite, 138–145.
        - Chemical composition and classification, 140–143.
          - Analysis and norm of bergenose, Norway, 142.
          - Analyses of gabbro-nelsonite, 140.
          - Norm of gabbro-nelsonite, 141.
        - Details of occurrences, 143–145.
        - Megascopic character, 138–139.
        - Microscopic character, 139–140.
        - Name and distribution, 138.
      - Genesis, 151–155.
        - Table of melting points of rutile, ilmenite, and apatite, 154.
      - Hornblende nelsonite, 133–138.
        - Chemical composition and classification, 135–137.
          - Analyses of hornblende nelsonite, 135.
          - Norms of hornblende nelsonite, 135.
        - Microscopic character, 134.
        - Name and lithologic character, 133–134.
        - Other occurrences, 137–138.
      - Ilmenite nelsonite, 106–117.
        - Chemical composition and classification, 109–110.
          - Analyses of ilmenite nelsonite, 109.
          - Norms, 109.
        - Details of occurrences, 111–117.
        - Distribution, 106.
        - Megascopic character, 106–107.
        - Microscopic character, 107.
          - Analysis of apatite from nelsonite, 108.
          - Analysis of ilmenite from nelsonite, 107.
      - Magnetite and biotite nelsonites, 123–133.
        - An exceptional facies, 130–133.
        - Chemical composition and classification, 124–127.
          - Analyses of magnetite and biotite nelsonites, 125.
          - Norms, 127.
        - Megascopic character, 123–124.

      - Microscopic character, 124.
      - Name and distribution, 123.
      - Other occurrences, 127–130.
    - Nelsonite, 100–106.
      - Distribution, 101.
      - General microscopic characters, 104–105.
      - Mineral composition, 103–104.
      - Name, 100.
      - Size, shape, and structure of the bodies, 102–103.
        - Varieties, 104.
      - Weathering, 105–106.
    - Rutile nelsonite, 117–123.
      - Chemical composition and classification, 120–122.
        - Analyses of rutile nelsonite, 120.
        - Norms of rutile nelsonite, 121.
      - Megascopic character, 117–118.
      - Microscopic character, 118–119.
        - Analysis of rutile from rutile nelsonite, 119.
      - Name and distribution, 117.
      - Other localities, 122–123.
    - Summary of quantitative classification of nelsonites, 155.
    - Syenite, 68–90.
      - Chemical composition, 75–78.
        - Analyses, 76.
        - Feldspar composition of syenite, 77–78.
      - Classification, 78–80.
        - Norms of syenite, 78.
        - Summary of quantitative classification, 78–80.
      - Contacts, 84–90.
        - Gneiss-syenite contact on the northwest side, 86–90.
        - Gneiss-syenite contact on the southeast side, 84–86.
        - Mars Mountain, 90.
      - Distribution, 70.
      - General statement, 68–69.
      - Megascopic character, 70–71.
      - Microscopic character, 72–74.
        - Analyses of uralite and hypersthene of the syenite, 74.
      - Variations in the syenite, 80–84.
  - General statement, 56–57.
  - Principal rock groups, 57–58.
- History of mining, 47–50.
- Literature, 52–56.
- Location, 42.
- Prices, 52.
- Production, 50–51.
  - Rutile produced in Nelson County, 1903–1912, 51.
  - Topography, 44–46.
  - Uses, 51–52.
  - Weathering, 46–47.
- Geology and petrography, Roanoke County area, 236–247.
  - Age, 247.
  - General statement, 236–237.
  - Genesis, 246–247.
  - Principal rock groups, 237.
- Geology, Graves Mountain, Georgia, 24–25.
- Geology of the ore deposits of Goochland and Hanover counties, 248–261.
  - Economic considerations, 258–261.
    - Commercial possibilities, 260–261.
      - Conclusion, 261.
      - Pegmatite rutile, 260–261.
      - Residual rutile, 260.
    - Mining developments, 258–260.
      - Bowe farm, 258–259.
      - Nuckols farm, 259–260.
  - General geology and petrography, 250–258.
    - Introductory statement, 250.
    - Principal rock groups, 251–258.
      - Diabase, 254.
      - Diorite, 253–254.
      - Gneiss, 251–252.
      - Pegmatite, 252.
      - Pyroxenite, 254–255.
      - Rutile ore, 255–258.
        - Age of the deposits, 258.
        - General character, 255–256.
          - Ilmenite, 256.
            - Analysis of ilmenite, 256.
          - Megascopic character, 255.
          - Microscopic character, 255–256.
        - Genesis, 257–258.
        - Mineral associations, 256–257.
        - Mode of occurrence, 256.
  - History, 248.
  - Location of rutile deposits, 248.
  - Topography, 250.
- Geology of the ore-deposits of the Roanoke County area, 235–247.
  - Age, 247.
  - Genesis, 246–247.
  - Geology and petrography, 236–247.
    - General statement, 236–237.
    - Principal rock groups, 237–246.
      - Diabase, 246.
      - Hypersthene-quartz syenite, 237–240.
        - Comparison with syenite of northern Blue Ridge, Virginia, 239–240.

        - Analysis of hypersthene akerite, Milam's Gap, 239.
      - General character, 237–238.
      - Microscopic character, 238.
    - Individual description, 243–245.
    - Nelsonite, 241–246.
      - General statement, 241.
      - Megascopic character, 241–242.
      - Microscopic character, 242.
    - Pegmatite partly of unakite composition, 240–241.
  - History and developments, 236.
  - Location and topography, 235–236.
- Georgia, 23–27.
  - Graves Mountain, 23–27.
- Gneiss, 251–252.
- Gneiss-syenite contact on the northwest side, 86–90.
- Gneiss-syenite contact on the southeast side, 84–86.
- Granite dikes, 201.
- Graphite, 229–230, 232.
- Graves Mountain, 23–27.
  - Analyses of rutile from, 26.
  - Geology, 24–25.
  - Location and topography, 23–24.
  - Rutile, 25–27.
- History, 1, 248.
  - and developments, Roanoke County area, 236.
  - of mining, 47–50.
- Hornblende nelsonite, 133–138.
  - Chemical composition and classification, 135–137.
  - Microscopic character, 134.
  - Name and lithologic character, 133–134.
  - Other occurrences, 137–138.
- Hypersthene-quartz syenite, 237–240.
  - Comparison with syenite of northern Blue Ridge, Va., 239–240.
  - General character, 237–238.
  - Microscopic character, 238.
- Igneous rocks, 14–15.
- Ilmenite, 7–8, 223–225, 256.
  - Analyses and ratios of ilmenite, 225.
  - Composition of ilmenite, 224.
- Ilmenite nelsonite, 106–117.
  - Chemical composition and classification, 109–110.
  - Details of occurrences, 111–117.
  - Distribution, 106.
  - Megascopic character, 106–107.
  - Microscopic character, 107.
- Incandescent media, 278–283.
- Individual description of mining properties, 161–197.
  - American Rutile Company's quarries, 161–173.
    - Composition of rutile concentrates, 172–173.
      - Commercial analyses of rutile concentrates, 173.
    - Geological relations, 163–170.
      - Diabase, 168–170.
      - Gabbro, 165–168.
      - Syenite, 163–165.
    - Location and history, 161–162.
    - Mining and milling operations, 170–172.
      - Analyses of tailings, American Rutile Company's ore, 171.
    - Production and uses, 163.
  - General Electric Company's mine, 173–193.
    - Areal geology, 176–193.
      - Diabase, 192–193.
      - Gabbro, 191–192.
      - Introductory statement, 176–179.
      - Nelsonite, 184–191.
        - Detailed description of occurrences, 184–191.
          - Composition of apatite, 189.
            - Analysis of apatite, 189.
          - Composition of ilmenite, 190.
            - Analysis of ilmenite, 191.
          - Composition of rutile, 190.
            - Analysis of rutile, 190.
      - Syenite, 179–183.
        - Detailed description of occurrences, 180–183.
  - General statement, 161.
  - The rutile ore, 193–198.
    - General statement, 193.
    - Nelsonite rutile, 196–197.
      - Composition of rutile, 197.
        - Analysis of nelsonite rutile, 197.
      - Megascopic character, 196–197.
        - Percentages of rutile ilmenite, and apatite in representative nelsonites, 196.
      - Microscopic character, 197.
    - Syenite rutile, 193–195.
      - Composition of the rutile, 194.
        - Analysis of rutile from syenite near Roseland, 194.
      - Megascopic character, 193–194.
      - Microscopic character, 195.
- Individual description, principal rock groups, 243–245.
- Introduction, 37–38, 202, 213–214.
- Introductory statement, 155–156, 176–179, 198, 231–234, 250.
- Kaolin, 232–233.
- Kragerö, Norway, 37–41.

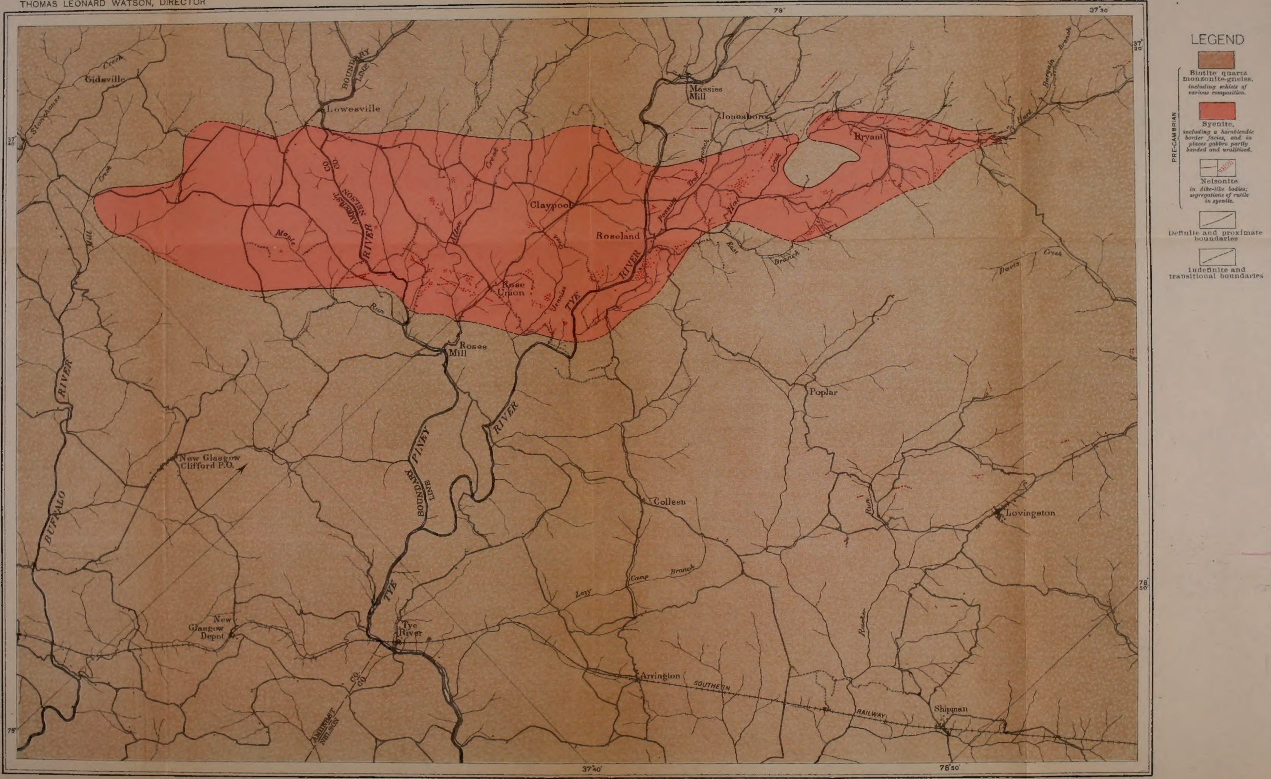
Kragerite, 37–41.
  Chemical composition and classification, 40–41.
    General description, 38.
    Introduction, 37–38.
    Microscopic character, 39–40.
Literature, 55–56.
Lithologic characters, 59–61.
Location, 42.
Location and history, 161–162.
Location and topography, Graves Mountain, 23–24.
  Roanoke County area, 235–236.
Location of rutile deposits, Goochland and Hanover counties, 248.
Lovingston district, 198–201.
  Introductory statement, 198.
    Amphibolite, 199–200.
    Biotite gneiss, 198–199.
    Nelsonite, 201.
    Pegmatite and granite dikes, 200–201.
      Granite dikes, 201.
      Pegmatite dikes, 200.
Magnetite, 8–9, 223.
Magnetite and biotite nelsonites, 123–133.
  An exceptional facies, 130–133.
  Chemical composition and classification, 124–127.
  Megascopic character, 123–124.
  Microscopic character, 124.
  Name and distribution, 123.
  Other occurrences, 127–130.
Maine, 20.
Mars Mountain, 90.
Massachusetts, 20.
Megascopic character, 196–197.
  Percentages of rutile, ilmenite, and apatite in representative nelsonites, 196.
Megascopic character, gabbro, 91–92.
  gabbro-nelsonite, 138–139.
  ilmenite nelsonite, 106–107.
  magnetite and biotite nelsonites, 123–124.
  nelsonite, 241–242.
  rutile nelsonite, 117–118.
  rutile ore, 255.
  syenite, 70–71.
  syenite rutile, 193–194.
Metamorphic rocks, 15–16.
Metallic alloys, 271–278.
Methods of preparation, 2–4.
Methods of preparing titanium alloys, 288–289.
  Cupro-titanium, 289.
  Ferro-titanium, 288–289.
Microscopic character, 39–40.
  Analysis of kragerite rutile, Kragerö, Norway, 40.
Microscopic character, biotite-quartz monzonite-gneiss, 61–63.
  diabase, 156–157.
  gabbro, 92–94.
  gabbro-nelsonite, 139–140.
  hornblende nelsonite, 134.
  hypersthene-quartz syenite, 238.
  ilmenite nelsonite, 107.
    Analysis of apatite from nelsonite, 108.
    Analysis of ilmenite from nelsonite, 107.
  magnetite and biotite nelsonites, 124.
  nelsonite, 242.
  nelsonite rutile, 197.
  rutile ore, 255–256.
  rutile nelsonite, 118–119.
    Analysis of rutile from rutile nelsonite, 119.
  syenite, 72–74.
    Analyses of uralite and hypersthene, 74.
  syenite rutile, 195.
Middle northern states, 20–22.
  New Jersey, 21.
  New York, 21.
  Pennsylvania, 21–22.
Mineral associations, 17, 256–257.
Mineral composition, nelsonite, 103–104.
Mineralogical characters, 213–231.
  Amphibole (uralite), 219–222.
  Apatite, 222–223.
  Biotite, 222.
  Feldspar, 216–217.
  Graphite, 229–230.
  Ilmenite, 223–226.
  Introduction, 213–214.
  Magnetite, 223.
  Olivine, 222.
  Other minerals, 230.
  Pyroxene (hypersthene), 217–219.
  Quartz, 214–215.
  Rutile, 226–229.
Mineralogical forms of titanium, 5.
Minerals occurring beyond the limits of the mapped area, 233.
  Allanite and sipylite, 233.
  Cassiterite (tin ore), 233.
Minerals occurring within the mapped area not previously described, 231–233.
  Galena, 232.
  Graphite, 232.
  Kaolin, 232–233.
  Sphalerite, 231–232.

- Mining and milling operations, 170–172.
  - Analyses of tailings, American Rutile Company's ore, 171.
- Mining developments, 175–176, 258–260.
  - Bowe farm, 258–259.
  - Nuckols farm, 259–260.
- Miscellaneous minerals, 231–234.
  - Ferruginous conglomerate, 234.
  - Introductory statement, 231.
  - Minerals occurring beyond the limits of the mapped area, 233.
  - Minerals occurring within the mapped area not previously described, 231–233.
- Miscellaneous uses, 287–288.
- Mode of occurrence, 14–18, 256.
  - Alteration of rutile, 17–18.
  - Mineral associations, 17.
  - Rock associations, 14–17.
- Mordants and dyes, 283–286.
- Name, nelsonite, 100.
- Name and distribution, gabbro-nelsonite, 138.
  - magnetite and biotite nelsonites, 123.
  - rutile nelsonite, 117.
- Name and lithologic character, hornblende nelsonite, 133–134.
- Nelsonite, 100–106, 196–197, 201, 241–246.
  - Detailed description of occurrences, 184–191.
  - Distribution, 101.
  - General microscopic characters, 104–105.
  - General statement, 241.
  - Megascopic character, 241–242.
  - Microscopic character, 242–245.
  - Mineral composition, 103–104.
  - Name, 100.
  - Size, shape, and structure of the bodies, 102–103.
  - Varieties, 104.
  - Weathering, 105–106.
- Nelsonite rutile, 196–197.
  - Composition of the rutile, 197.
  - Megascopic character, 196–197.
  - Microscopic character, 197.
- New England States, 19–20.
  - Connecticut, 19–20.
  - Maine, 20.
  - Massachusetts, 20.
  - New Hampshire, 20.
  - Vermont, 20.
- New Hampshire, 20.
- New Jersey, 21.
- New quantitative system of classification, 148.
- New York, 21.
- Norm of gabbro-nelsonite, 141.
  - kragerite (rutile aplite), Kragerö, Norway, 41.
- Norms, 65, 78, 96, 109, 121, 127, 135, 148, 158.
- Norms, Amherst-Nelson counties rocks, 210–213.
  - Norms of ore rocks (nelsonites) Amherst-Nelson counties, 212.
  - Norms of silicate rocks of Amherst-Nelson counties, 210–211.
  - Summary of classification, 211.
- North Carolina, 27–28.
- Norway, 37–41.
  - Kragerö, 37–41.
- Nova Scotia, 34.
- Nuckols farm, 259–260.
- Occurrence and character of rutile, Charlotte County area, 262–264.
- Occurrence and geographic distribution of rutile with description of areas, 14–41.
  - Geographic distribution of rutile, 18–41.
    - Australia, 34–36.
      - Queensland, 34–35.
      - South Australia, 35–37.
    - Canada, 31–34.
      - Nova Scotia, 34.
      - Ontario, 34.
      - Quebec, 31–34.
        - Other localities, 33–34.
        - St. Urbain deposits, 31–33.
          - Analysis of rutile-sapphirine-bearing ilmenite, 33.
      - Yukon territory, 34.
    - General statement, 18–19.
    - Norway, 37–41.
      - Kragerö, 37–41.
        - Chemical composition and classification, 40–41.
          - Analysis of kragerite (rutile aplite), Kragerö, 40.
          - Norm of kragerite (rutile aplite), Kragerö, 41.
        - General description, 38.
        - Introduction, 37–38.
        - Microscopic character, 39–40.
          - Analysis of kragerite rutile, Kragerö, 40.
    - United States, 19–31.
      - New England states, 19–20.
        - Connecticut, 19–20.
        - Maine, 20.
        - Massachusetts, 20.
        - New Hampshire, 20.
        - Vermont, 20.
      - Middle northern states, 20–22.

      New Jersey, 21.
      New York, 21.
      Pennsylvania, 21–22.
    Southeast Atlantic states, 22–28.
      Alabama, 22–23.
      Carolinas, 27–28.
        North Carolina, 27–28.
        South Carolina, 28.
      Georgia, 23–27.
        Graves Mountain, 23–27.
          Analyses of rutile from, 26.
          Geology, 24–25.
          Location and topography, 23–24.
          Rutile, 25–27.
    States west of the Mississippi River, 29–31.
      Arkansas, 29.
      California, 29.
      Colorado, 29–30.
        Analysis of rutile from St. Peter's Dome, 30.
        Analysis of rutile from West Cheyenne Canon, 30.
      South Dakota, 30.
        Analysis of rutile from the Black Hills, 30.
      Texas, 31.
  Mode of occurrence, 14–18.
    Alteration of rutile, 17–18.
    Mineral associations, 17.
    Rock associations, 14–17.
      Igneous rocks, 14–15.
      Metamorphic rocks, 15–16.
      Other forms of occurrence, veins, pegmatites, etc., 16–17.
      Sedimentary rocks, 15.
Occurrence, distribution and, titanium, 12–13.
Old system of classification, 148.
Olivine, 222.
Ontario, 34.
Other forms of occurrence, veins, pegmatites, etc., 16–17.
Other localities, 33–34.
Other localities, rutile nelsonite, 122–123.
Other minerals, 230.
Other occurrences, hornblende nelsonite, 137–138.
Other occurrences, magnetite and biotite nelsonites, 123–133.
Oxides, 6–7.
  Rutile, 6–7.
Partial chemical analyses of rutile, 228–229.
Pegmatite, 252.
Pegmatite and granite dikes, 200–201.
  Granite dikes, 201.
  Pegmatite dikes, 200.
Pegmatite dikes, 200.
Pegmatite, partly of unakite composition, 240–241.
Pegmatite, rutile, 260–261.
Pennsylvania, 21–22.
Percentages of rutile, ilmenite, and apatite in representative nelsonites, 196.
Possible effect of vanadium on color of rutile, 228.
  Partial chemical analyses of rutile, 228–229.
Preface, xv–xvi.
  Acknowledgments, xvi.
  Field work, xv.
  Scope of the report, xv–xvi.
Principal rock groups, 57–160, 237–246, 251–258.
  Areal distribution, 58–59.
  Biotite-quartz monzonite-gneiss, 59–68.
  Chemical composition of the nelsonites, 145–148.
  Classification, 148–151.
  Diabase, 155–160, 246, 254.
  Diorite, 253–254.
  Gabbro, 91–100.
  Gabbro-nelsonite, 138–145.
  Genesis, 151–155.
  Gneiss, 251–252.
  Hornblende nelsonite, 133–138.
  Hypersthene-quartz syenite, 237–240.
  Ilmenite nelsonite, 106–117.
  Individual description, 243–245.
  Magnetite and biotite nelsonites, 123–133.
  Nelsonite, 100–106, 241–246.
  Pegmatite, 252.
  Pegmatite partly of unakite composition, 240–241.
  Pyroxenite, 254–255.
  Rutile nelsonite, 117–123.
  Rutile ore, 255–258.
  Summary of quantitative classification of nelsonites, 155.
  Syenite, 68–90.
Production, 50–51.
  Rutile produced in Nelson County, 1903–1912, 51.
Production and uses, 163.
Pyroxene (hypersthene), 217–219.
  Analysis and ratios of hypersthene, General Electric Company's mine, 218.
  Composition and optical properties, 218.
Pyroxenite, 254–255.

VIRGINIA GEOLOGICAL SURVEY
THOMAS LEONARD WATSON, DIRECTOR

BULLETIN III-A. PLATE I.



MAP OF RUTILE AREA IN AMHERST AND NELSON COUNTIES, VIRGINIA

Scale: 1:62,500

1 ½ 0 1 2 3 4 Miles

1 ½ 0 1 2 3 4 5 Kilometers

1912